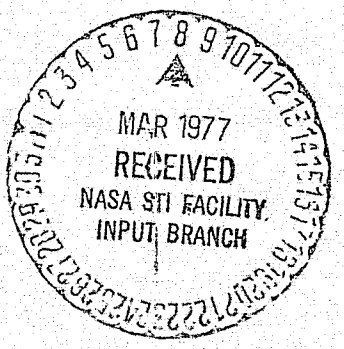
VOLUME I
TECHNICAL REPORT

FINAL REPORT
LOW COST PROGRAM PRACTICES
FOR
FUTURE NASA SPACE PROGRAMS

(NASA-CR-149656) LOW COST PROGRAM PRACTICES FOR FUTURE NASA SPACE PROGRAMS, VOLUME 1 Final Report, Jun. 1974 - Dec. 1975 (Lockheed Missiles and Space Co.) 65 p HC A04/MF A01 CSCL 05C G3/83

N77-17940

Unclas 16276



DECEMBER 1975

CONTRACT NAS W-2752

LOCKHEED MISSILES & SPACE COMPANY, INC.
A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION
SPACE SYSTEMS DIVISION · SUNNYVALE, CALIFORNIA

VOLUME I

TECHNICAL REPORT

FINAL REPORT
LOW COST PROGRAM PRACTICES
FOR
FUTURE NASA SPACE PROGRAMS

15 Dec 1975

Contract NAS W-2752

Prepared for :

NASA Headquarters
Washington D.C.

Prepared by :

Lockheed Missiles & Space Company Inc.
Space Systems Division
Sunnyvale, California

FINAL REPORT DOCUMENTATION

VOLUME I EXECUTIVE SUMMARY - "Low Cost Program Practices for Future NASA Space Programs."

VOLUME II APPENDIX - "Low Cost Program Practices for Future NASA Space Programs - Engineering Memoranda #2

Volume II includes:

Engineering Memoranda as follows:

LCPP-2. Impact of MIL-D-1000 Upon Space Programs, and Proposed Cost Improvement of Changes.

LCPP-3. Potential Cost Benefits Derivable from Changes to Ten (10) Selected Cost Driving Specifications.

LCPP-4. Specification Commonality Analysis for Six (6) Selected NASA Space Programs.

LCPP-5. A Plan for Establishing a NASA Central Specification Control Office (CSCO)

LCPP-6. A Low Cost Version of NHB 5300.4(1B) (Quality Assurance Provisions for Aerospace Contractors)

LCPP-7. Space Experiments Support Program 71-2; Program History and Spacecraft System Descriptions. *

LCPP-8. System Engineering & Integration (SE&I) Cost Impact Analysis.

LCPP-9. Ground Support Equipment (GSE) Cost Impact Analysis.

LCPP-10. Space Experiment Support Program 71-2; Cost Analysis.

LCPP-11. Space Experiment Support Program 71-2; Program Practice Analysis.

LCPP-12. Program Effects Relationships (PER) Survey.

LCPP-13. Specification Analysis; MIL-D-1000 (Engrg Drawings & Lists)

LCPP-14. Specification Implementation Commentary; MIL-D-1000.

LCPP-15. Assessment of Risk Impact; Low Cost Program Practices.

LCPP-16. MIL-STD-810B, MIL-STD-883A; Critical Review & Commentary.

LCPP-17. A New-Look Standardized Work Breakdown Structure (WBS).

LCPP-18 Proposed NASA Policy (Implementation) Directives - LCPP *

LCPP-19 SOTA Survey, Quantification of Program Risk.

LCPP-20 A Low Cost NASA Engineering Drawings & Lists Specification.

* Submitted to NASA separately. Not included in the Technical Report Volume.

FOREWORD

This Technical Report documents the progress and outcomes of NASA/HQ Study Contract NAS W-2752; an eighteen (18) month, in-depth analysis of NASA Program Practices. The study is the second of two conducted by Lockheed Missiles and Space Company Inc.; the first was undertaken in compliance with a contract let by NASA MSFC, and represented the initial attempt to quantify those practices routinely imposed by NASA upon aerospace contractors, which are, or have been, causative of significant increases in NASA Space Program Costs. While the first study identified, and to the degree possible, quantified NASA Program Practicesin the four program areas of Specifications, Documentation, NASA General Contracting Practices, and Program Definition; this second study examined those program areas identified, but not fully investigated in the previous undertaking. To that end, further analysis was conducted in the Program Specifications area, and an attempt was made to examine the Program Practices pursued in the areas of Systems Engineering and Integration (SE&I), and Ground Support Equipment (GSE). In addition, the study provides a preliminary example of a novel, more fully definitized Work Breakdown Structure, and a qualitative assessment of the Program Risks believed to be associated with the application of Low Cost Practices to NASA Space Programs. Both the WBS task, and the Risk Assessment arose from discovery during the first study, and the confirmation during the early stages of the present study; that:

(a) Current NASA WBS definition is insufficient to permit the detailed level of costing necessary to provide Program Managers with insight into exactly how, and where, program dollars are spent.

(b) Program managers have, and still do, express concern over the suspected increment in program risks attendant upon the implementation of Low Cost Program Practices.

During the course of the NASA/MSFC study, a Program Effects Relationship Handbook was produced in preliminary form. One of the tasks of this study was to determine, by NASA/Industry survey, Program Management reaction to the utility and application of such a Handbook. The results of this survey are treated in the main body of the report. The results/outcomes of all study tasks have been documented by Engineering Memoranda (EMs), released as each task was completed. All of these EMs form the text of the Appendix to this Volume, and they appear as they were written, in the informal style agreed as adequate by NASA.

TABLE OF CONTENTS

Section 1
INTRODUCTION

This study has been performed for NASA/HQ under the auspices and direction of the NASA/HQ Low Cost Systems Office. In the continuing NASA drive toward effective, Low Cost Space Programs, the Low Cost Systems Office (LCSO) monitored the study conducted under contract to NASA/MSFC closely. To a considerable degree, the investigation of Program Practices, and the evolution of lower cost alternates for the historical practices, depends upon the existence of adequate program records descriptive of historical practices. In some cases, for instance the investigation of the Cost & Practices aspects of SE&I, and GSE, resulted in the conclusion that data are insufficient to merit further inquiry into the subjects. In yet another case, the desire of NASA/HQ LCSO to verify Costs and Practices reported by another Government Agency, gave rise to a task of this study (Task 1). The completion of the MSFC funded study culminated in the production of a Program Effects Relationship(s) Handbook, hence a task of this study was to determine by NASA/Industry Survey the degree of acceptance and utility of such a program estimating tool. Thus, the study continues some tasks begun in the MSFC study, amplifies them, and furnishes results. Those tasks new to this study, and of specific interest to LCSO have been pursued to the degree believed profitable, and where curtailment has proved necessary due to lack of data to continue a given task; such a condition has been reported to LCSO. LSCO has issued re-direction of effort as necessary, and as suggested by LMSC. This Technical Report represents the study effort, both as originally envisioned and as re-directed.

1.1. STUDY BACKGROUND

This study covers the period June 1974 to December 1975, and as originally planned had four (4) major tasks:

Task 1 The compilation of Program/Cost Data Banks for the LMSCI spacecraft program P 71-2., and other NASA & DoD Space Programs.

Task 2 The conduct of Low Cost Program Practices analysis in five (5) areas of program technical interest; (1) Specifications, (2) Systems Engineering & Integration (SE&I), (3) Ground Support Equipment (GSE), (4) Program Work Breakdown Structures (WBS), (5) Program Risk versus Low Cost Practices assessment.

Task 3 Generation, data of value to NASA, for inclusion in a forthcoming NASA issued series of guidelines and instructions on Low Cost Program Practices (NASA Implementation Directives)

Task 4 The conduct of a NASA and Industry Survey to determine reactions to Low Cost Methodology, and to determine the potential acceptance, and utility of a PER Handbook; whose format and content would emphasize the use of Low Cost PERs when planning NASA space programs on a Low Cost basis.

The background giving rise to these tasks, and the subsequent re-direction of the study due to the curtailment of two (2) of those tasks is as follows:

1.1.1. Task 1 Background: At the outset of this study (approx. July 1974) USAF SAMSO issued a series of digests in the aerospace industry technical journals in which the claim was made that the USAF space vehicle test (STP) program was cost effective/low cost. NASA/HQ LCSO was interested in obtaining details of the program practices employed by USAF which permitted this claim to be made. As one of the USAF programs discussed in the published information was the LMSC program P-71-2, LCSO requested that this program be included in the study as part of Task 1. There were two reasons for the request/directive:

(1) Comparison of methods and costs of USAF programs vs NASA programs.

(2) Low Cost Hardware used for the P 71-2 program could be described for inclusion in the NASA Catalog of Available Standard Hardware (CASH), which was in the process of compilation under LCSO auspices.

In addition to the data for the P 71-2 program LCSO requested similar data for LMSC programs P-50, and P-95. LMSC applied for USAF permission to release

data,but due to the classified nature of both of these programs, the permission was denied. However the P 71-2 programmatic data was compiled and furnished to the LCSO in the form of three (3) EMs. EM LCPP-7, which dealt with the hardware disclosure, was delivered to LCSO separately, and hence is not included in this report, nor are EMs..... LCPP-10, the P 71-2 Cost Analysis, and LCPP-11, the P 1-2 Low Cost Practices Analysis. All of these EMs were delivered to LCSO as they were completed, and both #10 & #11 are included in the Appendix to this report. The overview of the information these two EMs contain is treated subsequently in Section 5 following, as is the subject of the study Data Bank.

1.1.2. Background, Task 2 This task encompassed five (5) areas of technical analysis. The first, which was concerned with specifications imposed by NASA for space programs, had its origins in the LCSO desire to explore further the cost driving aspects of specifications, which had been investigated in some depth during the course of the earlier MSFC study. The outcomes of this portion of task 2 are included, together with the highlights of the analysis, as Section 3 of this report. The second area of analysis was concerned with the general category of Systems Integration and the even more loosely defined discipline of System Engineering (SE&I). While no detailed investigation of this subject was undertaken during the course of the MSFC study, cursory examination of the cost category revealed that the costs acquired under this heading varied from program to program, from contractor to contractor, and the overall cost breakdowns were neither detailed, nor understandable. LCSO believed that an investigation of the SE&I area of interest would furnish some insight into means of effecting cost savings to programs. Even less detailed information exists for the GSE aspects of program costing. The usual practice has been to lump all GSE costs under a very general category, with no further breakdown as to costs, or disposition of the GSE after programs have been completed. LCSO thus approved the LMSC recommendation that this area merited investigation. Details of the outcomes of these studies are to be found in Sections 6 & 7 of this report. One of the difficulties besetting both the MSFC study, and this study has been the scarcity of detailed programmatic cost data. Although Work Breakdown Structures (WBS) have been employed as a cost acquisition/cost tracking/reporting tool, they have seldom contained sufficient detailed task data to permit either valid inquiry into what program activity has been under-

taken for some given level of activity funding, or what detailed work cost how much money. If it cannot be demonstrated that program costs per unit task are of some given order, then it is not possible to estimate with any accuracy the savings to be derived from the implementation of low cost practices. The "New Look WBS" task was proposed and undertaken to afford insight into such an area of interest, and the description of the task and its results are contained in Section 8 of this report, as well as EM LCPP-17, which furnishes details, and is contained in the Appendix. The Program Risk versus Low Cost Practices assessment was undertaken as a task arising from NASA/Industry concern over possible increases in program risk attendant upon the institution of Low Cost Program Practices. The concern of both NASA and Industry space program managers with the potential risks associated with the adoption of Low Cost Program practices, was voiced by almost all of the personnel interviewed during the course of Task 4, the PER Survey. Chronologically, Task 4 preceeded the accomplishment of the 5th of the technical inquiries; however since the concern over risk was so widespread as revealed by the PER Survey, this area of technical interest was accorded as detailed a qualitative treatment, as the availability of data on the subject permitted. The results of the qualitative risk analysis are summarized in Section 9 of this report, and EM LCPP-15, included in the Appendix, furnishes details.

1.1.3. Task 3 Background: By agreement with NASA/HQ LCSO this task consisted of the generation of a series of guidelines, and instructions on the subject of Low Cost Methodology in general, and Low Cost Program Practices in particular. These were to be used by H/Q in the preparation of Implementation Directives. Implementation directives is a generic term for those official documents concerned with Low Costs. As such,these directives are expected to form the subject matter of either Policy Directives, Management Instructions, or both. For this reason the LMSC data/guidelines/instructions are examples only, and are not included in the Appendix to this Technical Report. An EM, LCPP-18 has been prepared containing these examples, however, and this EM has been delivered to NASA/HQ separately.

1.1.4. Task 4 Background At the close of the MSFC prior study, LMSC prepared , and delivered to NASA/HQ copies of a preliminary PER Handbook. PERs may be

defined as an estimating device for program managers which shows the relationship of a given program practice, to program costs. Costs of customary practices were contrasted with Low Cost Program alternate Practices. In order to publicize the existence to this programmatic tool, and to not only improve the content of the handbook, but also gain ideas into what other PERS might be of value to NASA and industry program planners, and managers, a PER Survey was undertaken. The extent of this survey, the modus operandi for conducting it, the formal questionnaire prepared by LMSC for completion by the persons interviewed, and the outcomes of it, all are summarized in Section 4 of this report. Details of the survey, and an example of the questionnaire form the subject matter of EM LCPP-12, which is included in the Appendix.

1.2. Study Goals: The major goal of the study was to evolve by various means alternate program practices for NASA space programs, which, when implemented, would effect financial savings when considered versus customary practices which have proved to be cost drivers. The general goal had four subsidiary objectives as follows:

(1) By investigation, determine the cost impact of current NASA practices applied to hardware procurement, monitoring/control, development/qualification upon program costs at aerospace contractors. Such investigation was believed to be valuable in the identification of significant cost trends, and the determination of overal program cost effects.

(2) By analysis of space programs historical data, or equivalent data/proposals for near future programs, specific program procedures, or contractor-requirements changes causative of program cost, reductions could be identified.

(3) Determination of the cost reduction impact of Low Cost Practices, by means of historical data comparisons, or by a process of logical estimation. Such data were to be displayed in a manner designed to facilitate cost effective decisions for future space programs, by management personnel.

(4) Preparation of specimen documents, such as re-written versions of selected specifications. Such documents, styled to accomodate Low Cost methodology, and its implementation, could then be imposed by NASA on future space programs, with appreciable cost benefits as the result.

1.3. Study Scope: The span of the study was eighteen months, from June 1974 until Decemeber 1975, and the final report was to be prepared in the last month of the study.

The tasks of the study were 4 in number, as shown in the task outline appearing on Page 1-2. Task 2, the analysis of specifications, had five (5) subtasks which are discussed as to pertinence and background in Section 1.1.

All tasks were completed, and the outcomes were documented in a series of 19 Engineering Memoranda, LCPP-2 through LCPP-19. Copies of all of these memos were delivered to NASA as they were generated, and further copies of the series appear in the Appendix to this technical report, with two (2) exceptions. EM LCPP- 7, and EM LCPP-18. These two EMs had no direct bearing on the outcomes of the LCPP analysis tasks as such, for reasons stated in Section 1.1. and were therefore excluded from the Appendix.

1.4. Study Guidelines and Assumptions: One assumption was made, which pertained throughout the study, and six guidelines were proposed to NASA/HQ who concurred with these propositions. These are listed as follows:

1.4.1. Assumption: In all cases 1975 technology has been assumed adequate for implementation of improved, cost effective program practices, evolved as outcomes of the study.

1.4.2. Guidelines:

1.4.2.1. Cost impact areas selected for the study emphasis analyses will be those mutually agreed potentially profitable in terms of evolution of cost effective practices, by LMSC and NASA/HQ.

1.4.2.2. Spacecraft technology changes, will not be considered to influence the basic program practices under investigation.

1.4.2.3. The study will consider only un-manned, automated spacecraft programs. (This guideline was NASA/HQ directed)

1.4.2.4. Data prepared during the previous MSFC study, to be used for a starting point for the current study.

1.4.2.5. Those areas believed to possess the highest cost-saving potential will form the emphasis areas of this study.

1.4.2.6. Data to facilitate the new analysis areas of SE&I AND GSE are to be furnished by NASA, as are specification-tree listings. Other data available from such sources as the Library of Congress Scientific Data to be used, as, and where, pertinent.

SECTION 2

SUMMARY OF STUDY RESULTS

2.1. Study Results by Task: Each of the sixteen (16) EMs included in the Appendix to this report furnishes Conclusions and recommendations concerning the subject addressed by the EM. Further, each section of this report sets forth the outcomes of the tasks performed during the study. To facilitate understanding of the entire study task as a whole, this section 2 includes a very brief overview of the study tasks, and the major conclusions to be drawn when considering not only the tasks themselves, but the study as a whole.

2.1.1. Task 1 Overview: This task was undertaken during a period of roughly the first eight (8) months of the program, and was divided into two (2) parts. Part 1 consisted of amassing a complete technical description of the spacecraft and its subsystems. In addition to the technical performance description, and data sheets descriptive of the components used, sketches and drawings of the major components were compiled from program originals. All of this material was compiled into an EM giving the complete program history of the program, and, in two appendices Appendix A, & B, furnished Program Flight Data Reports, and Component Data Summaries. The main body of the EM was voluminous, consisting of 202 handwritten, but fully legible pages; and Appendices A & B consisted of 65 and 178 handwritten pages respectively. As NASA wished to obtain the component data as soon as possible for inclusion into CASH, and the page count was so large, the COR agreed to accept both the EM and the Appendices in handwritten state. By further agreement, since the program had received acclaim as Low Cost, and used Low Cost Program Practices in part , the EM was delivered early, and does not appear in the Appendix to this volume. Information from the COR stated that the EM was satisfactory as delivered (March 1975). The entire package was EM LCPP-7.

Part 2 of the analysis of this program P 71-2, covered the Program Costs Analysis, and the Program Practices analysis. Two separate EMs were written to cover these aspects of the analysis task; EM LCPP-10 for the Cost Analysis, issued May 15 1975, and EM LCPP-11 issued on the same date, covering the Program Practices Analysis.

In brief, the cost analysis was compiled from the program summaries, but with the additional feature that non-recurring costs were segregated from recurring costs,

for unit and operating cost categories; and the second feature of importance:- Within the subsystem costs, segregation was carried down to the "black-box" or major assembly level to provide as much functional detail as possible. The Program Practices Study for P 71-2 showed that high equipment, and design inheritance from one program to another contributes a major cost advantage, and contrasted 3 Low Cost Practices in nonrecurring costs versus their complementary high cost practices. A similar means of contrasting cost was employed in the unit recurring cost area. Disregarding the cost savings due to high inheritance, the analysis showed at least 21% of Total Program Costs (TPC) could have been saved by implementation of recommended Low Cost Practices. (For details see Appdx)

2.1.2. Task 2 Overview: This task may be considered as the main technical analysis portion of the LCPP study. As stated earlier in this report, it consisted of 5 technical areas of interest:

- o Specifications Analysis ... EMs 2,3,4,5,6,13, 14, 16.
- o Systems Integration and Engineering (SE&I) Analysis. EM 8.
- o Ground Support Equipment (GSE) Analysis... EM 9
- o Program Work Breakdown Structure (WBS) Analysis EM 17.
- o Program Risk versus Low Cost Practices Assessment ... EM 15.

The specifications analysis carried on throughout the program, with the first tasks being completed, and the EMs describing them delivered during the 1st 8 months of the program (EMs 2,3,4,5 & 6). At that time a review of the program was made by NASA/HQ and the decision was taken that further analysis in depth should be undertaken in the areas of MIL-D-1000, MIL STD 810B & MIL-STD-883A which cover Engineering Drawings & Lists, Environmental Test Methods, and Test Methods for Microcircuits respectively. MIL-D-1000 was completely re-written in a Low Cost version, and a draft of the re-write was furnished to NASA/HQ, at the occasion of the August 20 COR's visit to LMSC. An EM (LCPP-20) was written to cover the new version of the specification itself, and EMs 13, &14 were issued at the end of the month, the first being details of the analysis which contributed to the re-write of the document, and the second being an Implementation commentary. The final specificatior analysis of the two test oriented documents was completed during the month of September, and delivery of the EM, EM-16, was made during the early part of October 75.

The Systems Engineering & Integration (SE&I) Analysis was undertaken during the early phase of the program, except that the EM describing the task was not issued until the month of April, approx 9-10 months after the actual contract start. As the data search progressed during the first 5-6 months of the contract, it became apparent that data in a suitable form for cost impact analysis did not exist, and that contractor-to-contractor, little commonality of understanding of what the cost category implies appears evinced on past programs. For similar reasons the cost quantification and identification of Low Cost Practices was not possible; largely due to the incomplete and inconsistent record keeping in the areas of Program Definition, RFP, and WBS preparation. Some determinations of a general nature were possible however, and these appear in greater detail in Section 6 of this report, as well as in the EM LCPP-8 contained within the Appendix.

The GSE Analysis (GSE) This task was undertaken in parallel with the SE&I analysis. The first step in the task progression was to prepare a GSE questionnaire for circulation to NASA field centers and industry. The questionnaire was distributed to NASA centers and selected companies within the aerospace industry as follows: NASA AMES R.C., GSFC, MSFC. Industry: Boeing Corp, General Electric Corp, Hughes Aircraft Corp, Jet Propulsion Laboratories, Fairchild-Hiller Corp, RCA Corp, Philco Corp WDL, and TRW Corp. Of these, only Hughes Aircraft Corp, MSFC/TRW, GSFC/Philco, GSFC/RCA responded, and the response was not full in some cases. To augment these data, LMSC provided questionnaires to both the P 71-2 program office and the P-50 program office. The former did not reply, and the latter responded. The significant trend appears to be toward lower GSE costs, and this end is obtained by making maximum possible use of the GSE already in possession of contractors, so that high equipment inheritance program-to-program is maintained. The subject is treated in greater detail in Section 7 of this report, and details are contained in full in the EM LCPP-9 issued May 1 1975, a copy of which is in the Appendix.

The WBS Task Due to the pressure of continuing the tasks of specification analysis, SE&I and GSE analysis, and documenting the outcomes of the PER survey (see Section 4), the start of the WBS task was deliberately delayed. Further unforseen delays were occasioned by an accident injury to the LCPP program manager, under whose leadership the task was to be conducted; and the unavailability of personnel originally scheduled to perform the task. When work was commenced, it was believed that the LMSC version of the CSCSC technique,

CASPER, a computerized cost acquisition and tracking operation validated by the USAF; would be acceptable for use. CASPER provides excellent cost acquisition and summing capability for work packages traditionally used for WBS operation, where the cost computations are additive in nature. As the data search progressed, and the definition of the WBS task was expanded to include functional disciplines, and descending levels of cost detail, it became apparent that the overall computation, tracking, and reporting of all program effort costs was combinatorial in nature. When all possible permutations of the many combinations of functional task, and hardware/software production dollar cost acquisition methods was made, the total was of the order of 50,000. CASPER is not suitable to handle the combinatorial aspects of such a large order of cost allocation subsets, as the means for allocating costs to such a large number of chargeable areas is impractical, both from a cost-to-acquire, and the human problems inherent in logging the data, aspects. Resolutions for these problems, and the final scope of the task, together with its outcomes are detailed in Section 8 of this report, total detail being contained in EM LCPP-17 included in the Appendix.

The Risk vs Low Cost Practices Assessment Task This task arose from the outcome of the PER Survey which was LCPP Program Task 4; details of which are discussed in Section 4 of this report, and are amplified fully in EM LCPP-12 of the Appendix. One of the major concerns of those personnel from both NASA and industry responding the the PER questionnaire; was the increase in program risk suspected to result from the implementation of Low Cost Practices. A survey of current techniques for assessing risk revealed that these are of a probabilistic nature, and considerable data of the prior performace type are required, to manipulate and iterate the many mathematical models with any degree of surety of outcome. Therefore the approach taken to the assessment of programmatic risk implicit in the application of Low Cost Practices was to perform analyses of each Program Practice qualitatively. Data sheets were constructed, a sample of which appears in Section 9 of this report. These sheets list each practice, show the program area impacted by it, and furnish an assessment qualitatively in terms of High, Medium, and Low likelihood of an adverse cost impact. Risks are shown with respect to the classic affects on Performance, Schedule, and Program Cost. Finally, a Delta Risk assessment is given which shows whether or not application of a practice may impart an Increase, Decrease, or No Change condition to the program area(s) impacted. Outcomes are given in EM LCPP-15 included in the Appendix, and the highlights are contained in Section 4.

2.2. Major Conclusions:

2.2.1. General: In addition to the major conclusions listed below, each section of this report carries any recommendations necessary to amplify the contents of the section. In preparing the several sections of the report, illustrations have been included. These illustrations, whether tables, graphs, or other pictorial matter, portray the highlights of the data contained in the EMs which furnish the details of the study data.

2.2.2. Record Keeping: Throughout both the MSFC prior study, and this current study, a major difficulty has been the lack of good historical DETAILED program cost vs performance records. NASA-imposed record keeping requirements for aerospace contractors are in dire need of major overhaul, if good program cost visibility is to be achieved, and maintained throughout future programs.

2.2.3. Specifications: Specifications can, and do drive costs. However, it is not so much the affect of any one specification, as the interactive, and cumulative affects of the total specification "tree", and its subordinate hierarchy imposed as a routine practice; that contributes to program costs.

2.2.4. SE&I: Within the aerospace industry and NASA, there is no clear, universal definition of what constitutes SE&I program activity. Reported costs for such a loosely defined program activity vary considerably, and there is no clear assurance that NASA has received what was required for the money spent.

2.2.5. GSE: GSE is poorly reported as a cost item, and detailed cost data are either unavailable, non-existent, or both; program-to-program. However, from the data that are available (and as reported by those responding to the GSE survey) it may be inferred that:

(a) GSE inheritance from one program to another within contractors' facilities, can save program costs.

(b) The inheritance operation has been used with cost effective results on such programs as; MVM-73 (JPL-Boeing Corp), AE (GSFC-RCA Corp), P.71-2 (USAF-SAMSO/STP-LMSC)

2.2.6. Program Risk vs Low Cost Practices: From the qualitative listing of program risks associated with Low Cost practices it would appear that Program Manager concern with such risks is largely psychological, rather than tangible. However a valid method of assessing program risks prior to program outset is needed, to promote the adoption of Low Cost Practices by future NASA programs.

2.2.7. Standard Work Breakdown Structure (WBS): LMSC believes that a standard WBS is required for use with NASA programs. However, there is a very definite relationship which exists between the level of cost detail acquired/reported, and the complexity, overall cost effectiveness, and practicality of the acquistion/recording/reporting process. It is evident that the sheer magnitude of the cost acquition and work definition-by-package process, may well prohibit its use, from both an ease of handling, and cost viewpoint. What the optimum Standard WBS should be, in terms of scope and application could not be determined within the constraints of the schedule and funds available for this study.

SECTION 3

SPECIFICATION IMPACT ANALYSIS

3.1 Task Introduction: The specifications task for this study is a logical continuation from the task of similar name which was undertaken for MSFC in the previous study. Specifications documents, which by definition are those documents setting forth program requirements other than detailed performance parameters, tend to drive program costs. Appreciable savings can be effected if the specifications imposed by NASA are simplified, and reduced to only that minimum essential for satisfactory program performance/management. Perhaps among Low Cost Program practices, specifications imposition is the most simple to analyse, and modify; for three reasons:

(1) Specifications are imposed for all NASA programs, and are visible to all program personnel concerned.

(2) The psychological attitude of technical personnel toward specifications is that they are a "Necessary Evil", and thus any improvement in them, or reduction in their number, is desirable.

(3) Whatever costs are driven by a specification, relate directly to the document. If it is not invoked, the costs it implies are not incurred, at least to the degree the specification provides.

3.2. General Outline: The specifications analysis task was to a large degree directed by NASA/HQ. The overall task may be divided into three (3) sections as follows:

- o Analyses performed during the first 7-8 months of the study
- o Analyses completed by the mid-term review.
- o Analysis completed subsequent to the mid-term review, at which time, some re-direction of the specifications task was given by NASA/HQ.

Those analyses falling within the first category may be listed as follows:

EM-2 Impact of MIL-D-1000 Upon Space Programs, etc.

EM-3 Cost Benefits derivable from 10 Selected Specs.

EM-4 Specification Commonality for 6 Selected NASA Programs

EM-5 A Plan for a NASA Central Specification Control Office

EM-6 A Low Cost Version of NHB 5300.4(1B) (Quality Assurance)

Specification analyses undertaken and completed within the next work category are as follows:

o A complete re-write of MIL-D-1000, Engineering Drawings and Lists, was made, and copies were handed to the NASA/HQ COR who visited the LMSC facility on May 5/1975. This work was NOT made the subject of an EM as the decision was made to issue the specification as a document which could be used by NASA as written, if NASA so elected. (Later, EM LCPP-20 number was assigned to the spec)

o During the visit by the COR, NASA/HQ Reliability/Quality Assurance comments to EM-6 were furnished to LMSC. A response to these comments was prepared and mailed to NASA/HQ 10 days later, and after the mid-term review June 18/75, the EM-6, the pertinent comments by HQ/QA, and the LMSC responses to those comments were discussed with Mr George White; the NASA reviewing authority for Rel/QA.

Work in the third category was undertaken as follows:

o EM-13 Specification Analysis MIL-D-1000 was issued August 26/75

o EM-14 Specification Implementation Commentary was issued Aug 28/75.

Both of these EMs amplified the details of the analysis performed to complete the re-write of the MIL-D-1000 specification, and furnished also suggested means by which the specification might be implemented within NASA.

o EM-16 MIL-STD-810B, & MIL-STD-883A, Critical Review & Commentary was written, and issued September 30/1975.

This EM was the outcome of the last of the specification analysis tasks required by the study contract, and advanced copies of the completed EM were made available to NASA early in October 1975.

3.3. Specifications Task, Assumptions: Several Assumptions were made to facilitate the general specifications analysis. These are listed as follows:

3.3.1. Issue Dates: The particular specification under analysis is the latest current issue in all cases. However, where previous issues form a part of the specification/standard as in the case of MIL-STD-883A, all such previous issues were included in the analysis.

3.3.2. Sub-Tiers: To the extent possible/pertinent, all sub-tiers of a major specification were included in the analysis task, and the interactions were shown.

3.3.3. Cost Aspects of Analysis: In cases where cost aspects of specifications were not readily identifiable from programmatic data, it was assumed that LMSC estimates would be acceptable, provided suitable rationale was included to re-inforce the validity of such estimates.

3.3.4. Cost Quotations, & Dollar Savings: Wherever possible, cost information associated with the specifications analysis task is expressed in "Percentage of Total Program Costs (Percent TPC)" Where dollar figures have been quoted; i.e, cost per page of documentation, the dollar values represent those in use at LMSC.

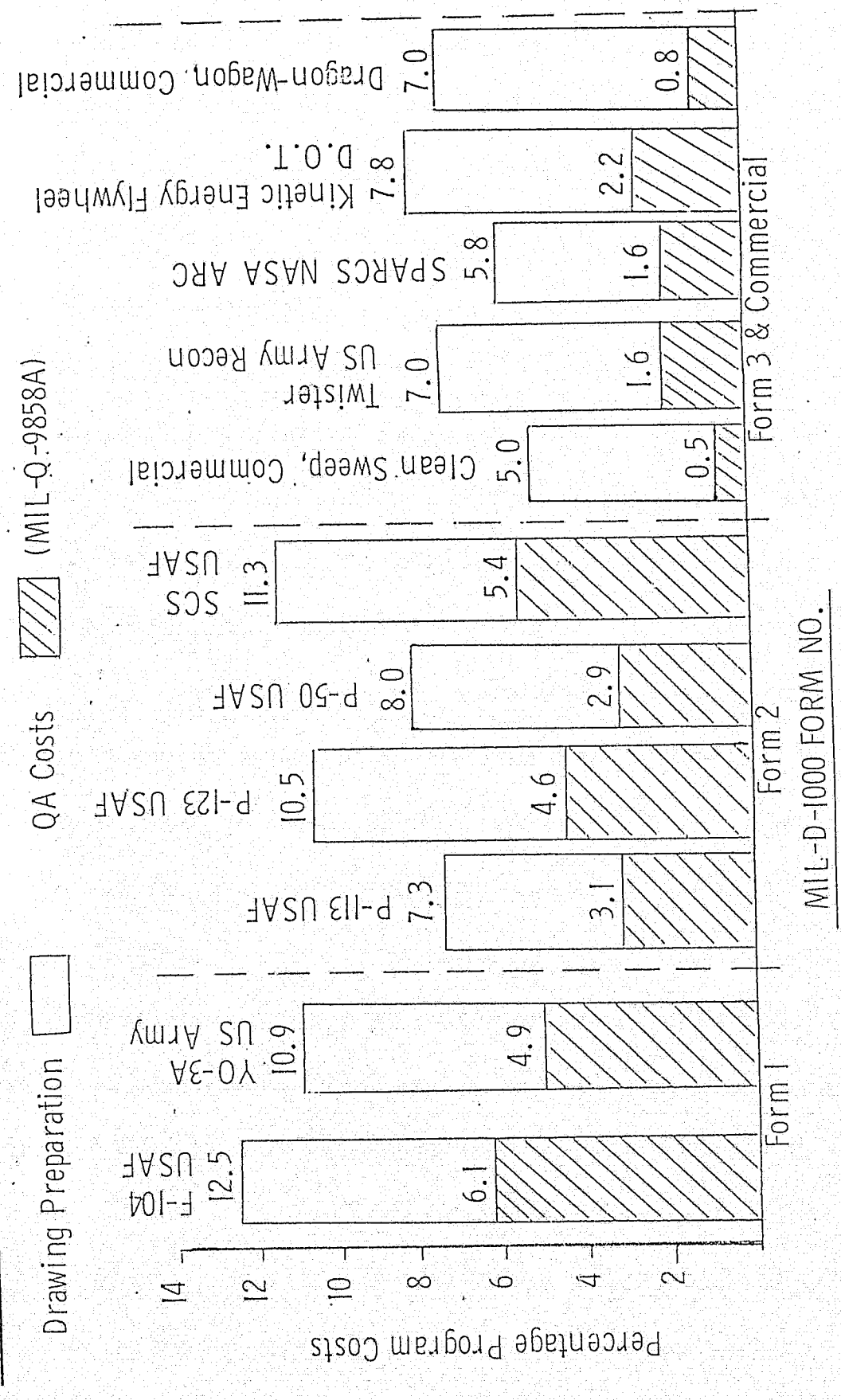
3.3.5. Terminology: As used in the analyis of all specifications examined, the term SPECIFICATION denotes any document containing requirements, OTHER THAN TECHNICAL PERFORMANCE PARAMETERS, routinely imposed on programs as a NASA practice.

3.4. MIL-D-1000, Engineering Drawings & Lists; Analyses: During the course of the MSFC study, a cursory examination was made of the cost impact on programs of the three forms, and 10 categories of drawings imposed by MIL-D-1000. At the outset of the current study NASA/HQ expressed interest in the MIL-D-1000 hierarchy of specifications, and the large sub-tier of documents comprising the hierarchy. An investigation was made of the specification, and the first of a series of EMs was issued on the subject, EM-2 issued January 7,1975, further detailed the preliminary work begun in the MSFC study, and charted the complete documentation tree showing the total dependency documentation list associated with MIL-D-1000. Also shown was the fact that if Form 1, the most costly and complex of the three Forms cited by the specification, is invoked; 38 sub-tier documents are also invoked. Similarly, in cases where Form 2 is specified, 12 sub-tier documents are involved also. Finally, should Form 3 be specified, only 4 sub-tier documents are automatically invoked. All of these data were applied, and based on several programs LMSC has conducted, a cost comparison chart was made showing both drawing costs for the three Forms, as well as QA costs associated with these Forms. The complete EM appears in the Appendix, but for ease of reference, Figure 3-1 is reproduced on Page 3-4 of this report.

3.4.1. MIL-D-1000 Re-Write: An outcome of the NASA Low Cost Specifications committee deliberations, was that LMSC should furnish a Low Cost version of the MIL-D-1000 document, incorporating all sub-tier documentation believed

TYPICAL DRAWING COSTS FOR MIL-D-1000 FORMS

Fig 3.1



pertinent to such a Low Cost version. This task request was conveyed to LMSC by the NASA/HQ COR at the Jan 21,1975 meeting at LMSC, and the task was undertaken. At the May 25 meeting copies of the Low Cost Version were handed to the COR, and as has been stated, the version was not written as an EM at first. The intent of the version, and the format adopted for it dictated this decission for the following reasons:

(a) NASA could use it directly for comments, and if favorable reactions were received impose it directly on programs.

(b) The format included rationale for the changes proposed in the restructured document, arranged in such a manner, that these rationale statements could be excised should NASA wish to impose the new version immediately.

Although the re-written specification was not given an EM no., initially, it appears in the Appendix, as EM LCPP-20, Dec 10/75,only to maintain continuity. Essentially, the new version shows how further cost savings beyond those realizable by imposition of Form 3 of the original document, can be effected. An example of such a savings is the use of sketched drawings, where the lines are not ruled, but all dimensions are furnished, sufficient to permit hardware to be made from the sketch.

3.4.1.1. MIL-D-1000 Analysis: On August 26 a short EM, EM LCPP-13 was prepared to furnish to NASA more details of the methodology used to perform the MIL-D-1000 re-write task, and the analytical details which emerged during the task. This sub-task was required by the Program S.O.W.

3.4.1.2. MIL-D-1000 Implementation Commentary: Also required by the S.O.W. was a short commentary to facilitate implementation of the Low Cost version of MIL-D-1000. This was prepared, and transmitted to NASA during the last week in August 75. This EM, LCPP-14 is included in the specifications section of the Appendix.

3.5. Analysis of 10 Selected Cost Driving Specifications: EM LCPP-3, included in the Appendix, treated the subject of Cost Benefits Derivable from Changes to 10 Selected Cost Driving Specifications. This task arose from a task undertaken during the course of the MSFC study which selected 20 specifications, and explored the degree to which these specifications drove program costs.

The premise was made for this analysis of the current study, that 10 of the 20 selected cost driving specifications could be changed to be more cost effective. If changes were made, to what degree could cost savings be realized, was the question that the analysis sought to answer. The analysis used two NASA programs of known low cost as the basis for estimation:

(1) MVM-73 (Although this was a JPL program, for purposes of the analysis, it was considered to be similar to any other program managed by a field center)

(2) Atmosphere Explorer (AE) GFSC and RCA Corp.

The format of the study analysis was to synopsize each of the 10 cost driving specifications briefly, to permit visibility into programmatic areas impacted by each driving specification. The next step was to estimate from programmatic cost data, the costs attributable to each specification. Low Cost changes were then prescribed for each of the specifications under study, and finally, the cost savings potential of each of these changes was estimated. Outcomes of this estimation process vs the suggested changes were compiled into a simple matrix. To permit visibility into the outcomes, this matrix is reproduced for reader convenience, and appears as Fig. 3.2. on Page 3-7.

3.6. Specification Commonality Analysis for 6 Selected NASA Programs: This analysis sub-task of the overall specifications analysis effort, was completed in January of 1975. EM LCPP-4 was written to describe the outcomes, and the EM was provided to NASA Jan 16 1975. The programs selected to be studied in terms of specification commonality were:

(1) Nimbus G. GSFC/General Electric Co

(2) Atmosphere Explorer. GSFC/RCA Corp.

(3) HEAO A/C. MSFC/TRW Corp.

(4) Pioneer-Venus. ARC/Hughes Aircraft Corp.

(5) MVM-73. JPL/Boeing Corp.

(6) P 71-2 USAF/SAMSO/STP... LMSC.

The original intention was to select 6 programs, but availability of program data was such that a JPL program, and the LMSC P 71-2, were included to make up the 6, in the absence of NASA data for 6 NASA programs.

3.6.1. Outcomes: It became obvious early in the analysis that very little commonality existed among specifications, program-to-program, each program tending

COST-DRIVING SPECIFICATION INVOKED/APPLIED	MVM-73 COSTS REPORT'D	MVM-73 SAVINGS EST'D.	ATMOS EXPL'R COSTS REPORT'D	ATMOS EXPL'R SAVINGS EST'D	ALL VALUES LISTED ARE IN PERCENT TPC* MAJOR COST REDUCING CHANGE APPLIED (ASSUMED)
NHB 5300.4(1A) Rel.	1.2	33% ① / 0.8 ②	1.3	38% / 0.8	Eliminate Parts Population Prediction. Use dynamic simulation. Eliminate Reliability Demonstration.
NHB 5300.4(1B) Qual	2.5	52% / 1.2	2.2	55% / 1.0	Delete Formal MRB Rqmt. Substitute informal MRB. Simplify Mgmt System. Reduce Reporting. Delete O.C.Curves. Simplify Inspection Instructions.
NHB 5300.4(1C) Insp	3.8	47% / 2.0	3.1	35% / 2.0	Inspect at Highest Possible Level. Use Double Sampling. Minimize Insp'n points in process.
NHB 5300.4(3A)Solder	1.4	46% / 0.75	2.1	60% / 0.8	Eliminate NASA certif'n for contractor solderers & inspectors. Approve process/training only. Update spec to include latest illustrations.
NHB 6000.1(1A) Pkg'g	0.15	33% / 0.1	0.2	25% / 0.15	Eliminate this General Specification. Detail Rqmts in S.O.W. per mandatory minimum.
Test MIL-STD-883 Methods	7.9	16% / 6.6	7.3	16% / 6.1	Limit Life Testing. Limit Rqmts for XRay Tests. Limit Test Repetitions. Specify Mimima not Max'a.
Config'n NPC.500.1 Mgmt.	0.35	43% / 0.2	0.8	25% / 0.6	Eliminate Batch Traceability. Elim. Mat'l Certs. Simplify numbering & Codes. Apply only for ≥3 S/C
Envir'l Test. MIL-STD-810B	3.2	56% / 1.4	3.9	62% / 1.5	Eliminate Thermal Vac at syst level. Apply at box lvl.Minimize Test Repetitions. Limit duration
Interch'ly MIL-I-8500	0.2	50% / 0.1	0.25	40% / 0.15	Limit to Programs with several S/C. Std'ze parts & components. Use Std Designs as possible.
Eng Dwgs & Lists MIL-D-1000	6.8	40% / 4.08	6.60	40% / 3.96	Reduce Form call out frm Form 2 to Form 3. Limit No. of Copies. Simplify QA & Insp Rqmts
Spec Contrib'n to Program Costs	27.50	37% / 17.23	27.75	38% / 17.11	① Percent Savings due to Changes
TPC Potential Svgs. △	10.3%	$3.9M	10.64	$2.34M	② New, Reduced Percentage of TPC.

* TPC = Total Program Costs

Fig.3.2. Affect on Program Costs of Specification Changes

to "Go its own way" with respect to the specifications imposed upon the program contractor. Cost implications were difficult to determine with any accuracy, with one exception. In the area of Product Assurance, sufficient general cost data were available to permit the estimation of assurance costs as a percentage of the total program costs. Therefore, a simple commonality Matrix for the specifications was constructed, and this appears as a three page tabulation in the EM, and together with this, a tabulation of assurance costs was provided. To this cost tabulation of assurance estimates were added verbal estimates from MSFC, and ARC, concerning their on-going programs, and since these do not have the advantage of "All costs are in" credibility, costs for OSO-I, and ATS-F programs were added. This cost tabulation appears below:

Program	Contractor/Center	Assurance Costs %TPC.
MVM-73	Boeing/JPL	6.1
AE	RCA/GSFC	3.1
Pio.Venus	HAC/ARC	5.5 (est. prog current)
Nimbus G	GEC/GSFC	6.2
HEAO	TRW/MSFC	6.0 (est. prog current)
P71-2	LMSC/USAF	5.1
OSO-I	HAC/GSFC	5.6
ATS-F	Fairchild/GSFC LMSC Flex-Rib antenna.	8.4

Some reccomendations were made in the EM, two of which gave rise to other tasks within the overall specification analysis portion of Study Task 2. these two are:

(1) Revise the NHB 5300.4 (1B) & (1C) Quality Assurance ; Inspection Specifications.

(2) Plan, and Institute, a NASA Central Specifications Control Office

The first recommendation formed the subject of EI LOPP-6, and the second form-

ed the basis for EM LCPP-5. (Per information received from the NASA/HQ COR at the May 5th meeting, NASA is proceeding with the institution of a Central Specification Control Office.)

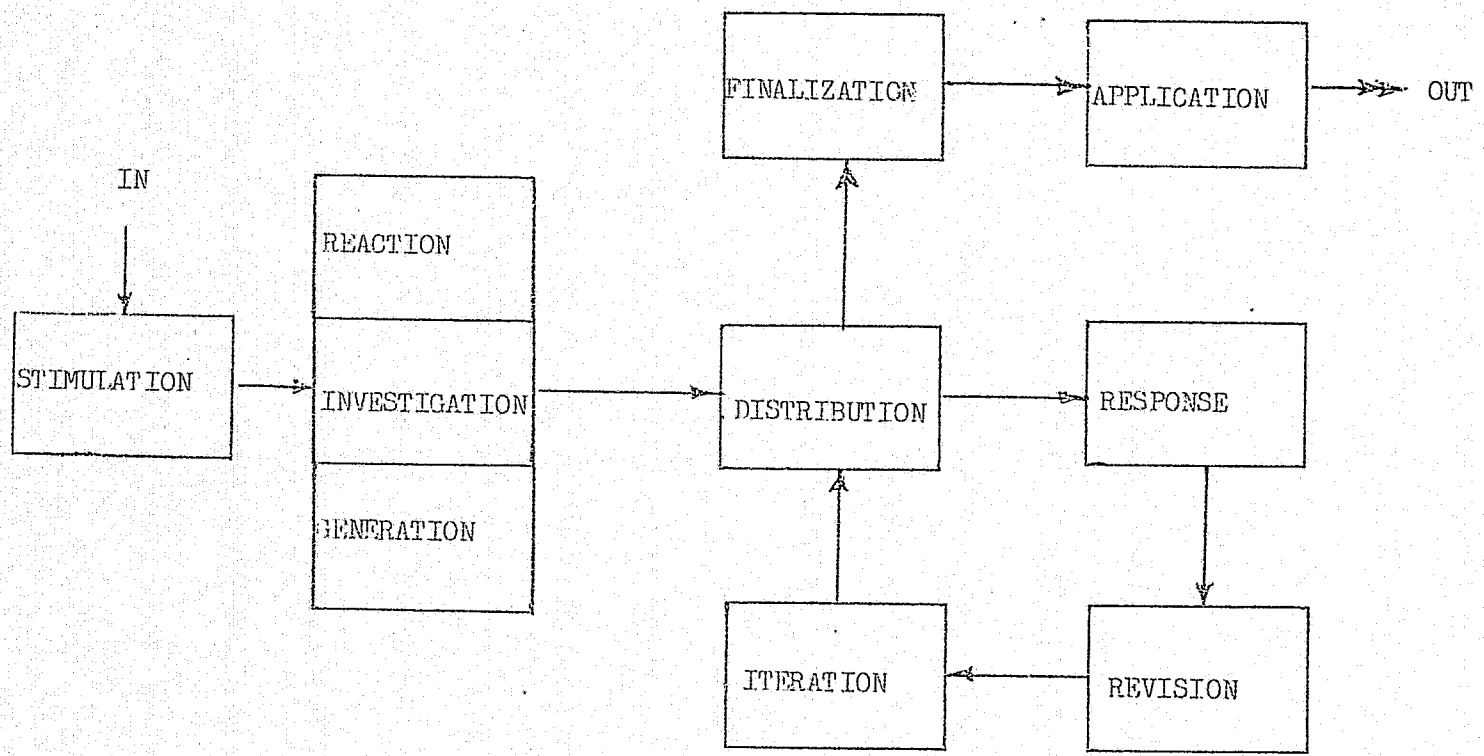
3.7 A Plan for A NASA Central Specifications Control Office (CSCO):

3.7.1. Analysis Overview: Arising from the specifications Commonality analysis, this plan was undertaken to indicate to NASA/HQ the need for such an office, and a method by which such might be instituted. The EM written to describe this planning was in two parts. The first part depicted the current state of affairs in both NASA and the DoD, and showed the relationship of NASA to the NASA and Tri-Services Review Board, highlighting the fact that NASA gains very little advantage from participation in the Board. The specification release, and modification system was graphically illustrated. In part two, functions of the CSCO were outlined by an illustration of a functional flow diagram. In addition to the function flow diagram, a graphical representation of the aims and objectives of the CSCO was presented, together with the systemic process of the office, and a detailed multi-path work flow diagram. The systemic logic underlying the functions and work-processes, was described, and all of these planning data were incorporated in EM LCPP-5 issued April 10/75. Much of the planning data included in the EM is graphical in nature, and for sake of brevity is not included here, as the EM is part of the Appendix. However, a diagram of the systemic process is shown as Figure 3.3. Page 3-10, to facilitate understanding of the operation of the proposed CSCO.

3.8 Critical Analysis & Commentary, NHB 5300.4(1B): As originally envisioned, the objective of this task was to re-write NHB 5300.4(1B), combining within the re-written version, the main elements of NHB 5300.4(1C) so that a composite document embodying both Quality Engineering, and Inspection Services would result. Discussion with the NASA/HQ COR in January of 1975 amended this task to combine the main elements of both the existing documents, but instead of re-writing them, a detailed commentary with recommendations for changes was to be the task output. The documents are arranged by chapters, and within the chapters paragraphs are ordered in numerical sequence. Each paragraph has a letter designator preceeding the numeral; viz:- Chapter 5, 1B502 Procurement Documents. The approach to the task was to analyse the contents of the documents paragraph

FIG. 3.3. Central Specifications Control Office

Systemic Process



-by-paragraph, giving the current statement of the paragraphs in an "Is" column, and a "To Be" column in which the recommended changes, and the rationale supporting them are given. This approach resulted in a tabulation of 14 pgs in length, an excerpt of which is furnished below:

Chapter 'Is Now'	Chapter "To Be"
1B701 Inspection & Test Planning: Sets forth the aims and intents of the Inspection and Testing Operations to be provided by the contractor, & his suppliers.	1B701: Again, the statements are general in nature. They state what is required of the contractor, not what is required as specific activity by his QA personnel/organization. This clause has three actual functions involved (1) Inspection Services. Provides Inspection (2) Test Operations. Plans, Executes Tests (3) Design Engineering: Design sets test limits The QA function is again one of surveillance to determine compliance only, NOT as has been the case, effectors. Recommend: Delete Paragraph/ Re-write to state Quality finite functions.
1B702. Test Specifications: Covers the provision, and preparation of test specs. States what specs are to include.	1B702. Covers the entire gamut of rqmts. Includes Environments, safety, reliability, test parameters & tolerances, adjustments, rework, repair, maintenance, data recording and analysis, re-test, and test results reporting. Role of Quality is only to assure that specs generated include such variables. Recommend: Re-word to show specific quality responsibility only.
1B703. Inspection and Test Procedures. Covers the provision of suitable procedures for regulation of these operations and specific instruction of operating personnel assigne . Give a 13 point outline of content required.	1B703. The inference can be, and in the past has been made, that a contractor's quality organization is to carry out the activity described as necessary in provision of these) procedures. Of the 13 points covered, only item 13 Non-conformances is of direct concern to QA. The others concern Test Ops & Planning, Engineering, Safety Engineering, and Inspection Services. The QA function is to assure procedures are available and contents are as prescribed. Recommend: Deletion, and relocation of rqmts in test, ispection, & safety documents; or re-write to show specific QA responsibility.

The second part of the analysis was an attempt to show costs associated with Quality Assurance to programs where either NHB 5300.4(1B), (1C), or the DoD Quality Specification MIL-Q-9858A was fully implemented during the program, and some of the economies possible.

A Quality Costs Tabulation was made of some cost statistics on typical space programs in the 50-100 million dollar range, as follows:

Quality Programs, General Statistics

1. For typical space programs in the 50-100 million dollar range, Quality Costs range from 7-11% total program costs (TPC).
2. Quality Costs for typical programs range from 34-45% of Manufacturing Costs
3. Typical Space Program Quality Engineering Costs range from 23-37% of Total Quality Program Costs.

   Typical Space Program Inspection Services Costs range from 63-77% of Quality Program Costs.

   Typical Ratio, Quality Engineering (QE) to Inspection..... 1:3 approx.
4. Economies Possible: Atmosphere Explorer (GSFC/RCA) Quality Costs 3.8% TPC Attributed to: Integration of Quality/Inspection, Reliability, and Configuration Management, effort & planning into one overall program activity.

Finally, Quality Engineering, and Inspection tasks performed on a typical program, were broken out by task, and referenced by specification paragraph, giving the Percentage of Quality Program Costs for both sets of detailed -tasks, and the full Quality Engineering Program, and Inspection Program Costs as Percentages of Total Program Costs. For ease of reference, this table is reproduced herein as Figure 3.4, Page 3-13. (The complete EM for this task, which contains the data reproduced partially herein, is included in the Appendix)

Ref	Major Quality Tasks; Typical Quality WBS (internal)	%QPC	%TPC
1B206	Quality Management	1.55	
1B501	Vendor/Supplier Surveys	0.55	
1B300/500	Quality Documentation (Preparation & Updates)	4.00	
1B205	Quality Audits	0.35	
1B206	Quality Planning (Inspec'n & Test, Work-flows & Plans)	1.20	
1B300	Quality Liaison (Engrg & Engrg Support Services)	2.40	
1B600	Quality Liaison (Mfrg, & Mfrg Support Services)	7.10	2.5
1B703	Quality Liaison (Test Operations, & Test Support Svcs)	2.20	
1B706	Quality Data Retrieval, Reduction, & Reporting	3.50	
1B703	Inspection Services Liaison	3.20	
1B801	MRB & Corrective action Follow-up. (average only)	1.50	
1B905	Measurements & Stds Lab, Liaison & Control	0.25	
1B202	Quality Training, & Certification	0.70	
1B805	Customer (NASA) Liaison	1.50	
Ref	Major Inspection Svcs Tasks; Typical QWBS (internal)	%QPC	%TPC
1B701	Inspection Services Management	2.25	
1B202	Inspectors Training & Certification	2.50	
1B704	Quality Engineering Liaison	3.20	
1B506	Receiving Inspection	12.50	
1B600	In-Process Inspection	26.40	6.0
1B705	End-Item/Final Inspection	5.15	
1B704	Test Surveillance	12.50	
1B801	Non Conformances Reporting	3.50	
1B1101	Pre-Shipment & DD-250 Inspection Activity	1.25	
1B905	Calibration Inspection (Measurements & Stds Lab Liaison)	0.50	

Fig. 3.4 Quality Engineering & Inspection Costs of Major Tasks

The EM, LCPP-6 was furnished to NASA/HQ in early March 1975, and at the May 75 meeting at LMSC, the COR presented a written list of comments on the Critical Analysis. These were prepared by the NASA/HQ Director of Reliability & Quality Assurance. As might be expected, the reaction to the Commentary was mixed, with both commendatory comments, and criticism included in the review.

Essentially, the review was favorable, applauding the idea of amalgamation of both the Quality and Inspection documents into one volume, but criticizing the deletion of some of the well-established quality functions such as reduction of the number of inspections per program. At the request of the COR, a detailed response was prepared to the NASA/HQ comments, and at the mid-term review in June, the entire commentary, NASA review, and LMSC reply, were discussed with the HQ Director of Reliability and Quality Assurance. A consensus of opinion was reached, to the effect that the LMSC commentary would furnish a major point of departure for the re-write of the Quality and Inspection documents which NASA expects to undertake internally.

3.9 Critical Analysis and Commentary, MIL-STD-810B, & MIL-STD-883A: This analyis was the final specification analysis of the study, and perhaps the most difficult to perform.

3.9.1 Objective: The objective of this task was to highlight the anomalies and overlaps existing between the two documents; show that much of the contents of MIL-STD-810B, Environmental Test Methods are not applicable to spacecraft; and indicate that the MIL-STD-883A document prescribes to a large degree, the Test Methods that apply to microelectronic devices, thereby making unnecessary further testing to comply with MIL-STD-810B.

3.9.2. Analysis & Commentary Approach: For both of the documents the approach taken was to review each of them by section and paragraph. Each paragraph was synopsized in the EM written on the entire analysis (EM LCPP-16 issued Sept 30 1975), and to each paragraph synopis was appended a Comment statement. The comments briefly considered the pertinence of the paragraph under review, suggested changes to improve cost effectiveness, where such changes appeared feasible, recommended deletion in instances where this appeared advisable, and explored the overall costs associated with the two documents as applicable to two programs; MVM-73 and AE. These two programs were selected since they were among the earliest to make wide use of microcircuitry, and microelectronic devices, and were programs undertaken during the period when the micro-devices state-of-the-art was still maturing.

3.9.3. Test Cost General Summary: One of the cost drivers to both the programs considered was Space Simulation Testing, as prescribed in MIL-STD-810B. A general test cost-summary for these two programs was synthesized from the cost

data available, and for convenience this summary is reproduced below:

	Total Test Costs %TPC	Ttl. Env Test Costs	Ttl Space Sim Costs
MVM-73	18.0% TPC	3.8% TPC	1.7% TPC
AE	16.2% TPC	4.0% TPC	1.9% TPC.

The inference was made from the costs above that had not space simulation testing been conducted, a savings to both programs of 1.7 & 1.9% TPC might have been realized. For programs of roughly 100 million dollars, ≈2 million saving is an appreciable figure. At present considerable controversy surrounds the subject of space simulation testing, and opinon appears polarized, as to the efficacy of such testing. LMSC is of the opinion that if such testing is required at all, it should be on a limited scale, and at the component level only. Testing of microelectronic devices is a matter of multiple replications, and while a cursory examination of the costs attributable to MIL-STD-883A required testing was made, the data are of considerable dubiety. EM LCPP-3 (which see) inferred that such test costs could amount to 7.5% of TPC, but this value is difficult to consider as a normative figure, as high mortality-rate of microelectronics, and associated high costs, undoubteldly were distorted due to maturation of the state-of-the-art by which the devices are produced. It was further inferred in EM-3 that 1.5-2.5% TPC might have been saved by elimination of one or two steps of test replication. NASA found it necessary to establish line certifiction methods to improve the yield of the micro-devices, and in the early days of production such certification was necessary. Currently, some of the certification testing is no longer needed, as major improvements in the state-of-the art have been effected. The savings figure would appear to be reasonable therefore, or even conservative.

3.9.4. Outcomes: The major outcome of the analysis was a series of specific recommendations, which for reader convenience, are listed below:

- o Review and combine the two standards into one conjoint NASA standard, to cover all aspects of environmental testing at all hardware levels.
- o Specify in the RFP, or other contractual document, exactly the type and level of testing the Government requires to be performed. Make the contractors' test plans the binding documents, for type, level, replication, and schedule for all testing performed.

- o Standardize device testing to the maximum extent possible, with respect to methods, replications, sample sizes, parameters, et al. The current test methods and standards tend to be too general.
- o Minimize test replications to the maximum extent possible, and in all cases where a test at the next higher assembly level will suffice to demonstrate merit, use this technique to curtail the test load.
- o Minimize/standardize the amount of test data reporting, and test documentation required at all program levels.
- o Assure that Quality Assurance and Reliability requirements specified are adequate for program assurance/validation, rather than the maximum possible, as is the current practice.
- o Standardize the number of devices available for a program, and do not design new ones merely for the sake of doing so.
- o Until such time as the present MIL-STDs controlling testing are re-written, and re-issued, ensure that these documents imposed to control the overall program test process are the latest issues available, and that a list of tests not required (Test Exception List) is appended to each purchase order; particularly at the basic device level.

SECTION 4

PROGRAM EFFECTS RELATIONSHIPS (PER) SURVEY

4.1. Task Objectives: At the close of the MSFC study, LMSC had completed and delivered to NASA a Per Handbook (preliminary). PERs are line graphs, bar charts, data tables, and families of curves which identify, and portray the key parameters of alternative practices, both management and technical; within a general program practice area. These parameters and their relationship to program costs were expected to serve as an estimation tool for senior program planners, and decision making personnel, so that relative costs of historical practices could be contrasted with alternative low cost practices, and estimates of potential savings could be made. The objective of Study Task 4 was to determine by means of a NASA/Industry survey, the potential acceptance of such a tool, the utility of a PER Handbook, and to obtain suggestions for new PERs of value to the expected users.

4.2. Task Approach: A two-step approach was used to attain these objectives:

(1) Prepare a comprehensive PER Questionnaire, for either hand delivery, or mailing to participants in the PER Survey.

(2) Personal Interviews with, and/or seminars for, the Survey participants to obtain first hand information concerning the PERs.

Interviews planned and accomplished were as follows:

- o Ten (10) NASA Field Center Project/spacecraft managers
- o Ten (10) NASA Field Center functional Division Managers
- o Three (3) NASA/HQ Program Managers (OSS, QA, OMSF)
- o Nine (9) Industry Program/Functional Division Managers representing at least 5 companies.

Interviews were conducted at NASA facilities, and those of the responding industrial companies, by personnel of the LCPP Study working as a two man team. An 18 page multiple choice questionnaire was designed which included Practices Areas, Cost Impacts, and Priority Ratings for all programmatic areas of interest; and a foreword to the participants guaranteed them anonymity if they so desired. Instructions were included in the foreword to assist in the completion of the document (LMSC-D387544), with stress on the fact that respondents were encouraged to give free expression to their views, by adding comments in spaces provided, in addition to completing the multiple-choice block entries.

4.3. Survey Results: Most of the survey interviews were conducted during the months of November and December of 1974, with some few interviews in January and February of 1975. As was anticipated, there was an appreciable lag in the time from interview until the completed questionnaires were received, although many of the interviewees completed the questionnaires and returned them during the course of the interviews. NASA and Industry participants were as listed below; and the number of completed questionnaires is included:

NASA	
Ames R.C.	5
GSFC	6
JSC	9
MSFC	7
NASA/HQ	2
Total	29

Industry	
Hughes Aircraft Corp	2*
JPL	6
LMSC	2
Martin Corp (Denver)	3
Philco WDL	3
Systems Devel. Corp.	1**
TRW Corp	3
Total	20

* Selected teams of personnel prepared two (2) questionnaires.

** Only one questionnaire requested from this source.

4.4. Survey Final Outcomes: EM LCPP-12, compiled and delivered to NASA April 21, 1975, contains not only the statistical analysis of the results, but also a complete questionnaire upon which appear the scores per each question. This EM (included in the Appendix in its entirety) when completed, led to a number of conclusions and recommendations being made to NASA/HQ.

4.4.1. Conclusions: Due to the length of the conclusions section of the EM only highlights are presented herein; they are:

- o Only 18% of the survey participants believed that the historical data in their company/center was adequate for the generation of meaningful PERs (meaningful = accurately quantified).
- o The PER Handbook idea is basically sound, but data preclude its amplification at present. Opinion on its use was polarized, with many respondents averring that the handbook would not be used.

- o Risk considerations inherent in the use of Low Cost Practices, and the lack of PERs capable of quantifying these risks, was of considerable concern to NASA personnel.
- o Industry personnel were strong in the opinion that their companies would do what is required of them by NASA, as stated in the program RFP, and PERs are of secondary importance to that aim.
- o Handbook format was believed to be satisfactory as LMSC had presented it.

4.4.2. Recommendations: As an outcome of the statistical analysis of the survey results, and the opinions expressed by the respondents, LMSC drew 8 major conclusions, the first three of which were discussed with NASA/HQ at the mid-term review in June 1975, and had a direct bearing on the remainder of the study. The conclusions appear below in synopsis form:

1. Discontinue development of PERs
2. Start immediately to develop a Work Breakdown Structure (WBS), capable of accurate quantification of Low Cost Program Practices in future space programs.
3. Evaluate Risk Impacts of potential Low Cost Practices, also to begin immediately.
4. Include Low Cost Practices in future program RFPs.
5. Continuing quantification of Low Cost Practices to be undertaken by NASA personnel.
6. Follow up the PER Survey with an Aerospace Executive Level Survey on Low Cost Practices.
7. If item 6 is implemented, prepare an Orientation Brochure and Survey Questionnaire, using results of this study and others as inputs.
8. NASA should institute an Education/Promotion program at field centers, to facilitate the use of Low Cost Practices.

SECTION 5

DATA ACQUISITION, (STUDY TASK 1)

5.1 General: The Data Acquisition Task, Study Task 1, had as its objective the collection of programmatic data from NASA/HQ, NASA Centers, DoD, Industry, and other sources, suitable for examination and excerption to facilitate the identification of Low Cost practices. In addition to those data which formed the Data Bank for the MSFC study, data were sought which had particular pertinence to the study of practices related to SE&I, GSE, and cost collection by means of a WBS.

5.2. Data Types Available: Due to the interest in the P 71-2 Program (LMSC/USAF) expressed by NASA, as complete a data package as possible was collected from Program Office records of this program. As explained earlier in this report these data were instrumental in the preparation of EM-7 which researched the program history of the program performance, and reported:

- o Program history (technical)
- o Lists and descriptions of Program Components
- o Cost data for program components
- o Programmatic cost data to permit analysis of (a) costs,(b) routine practices applied vs low cost practices.

5.2.1. MVM-73/JPL/Boeing: Contact was made early in the program with JPL Pasadena Calif, and this organization provided fairly complete data on the performance of the subcontractor Boeing Corp. While data concerning the JPL cost breakdown for the program were considered essential to the analysis of this Low Cost program, and its practices, LMSC was unable to obtain a cost breakdown which decribed the contract performance costs for the JPL in-house effort. A data file on this program, as complete as NASA/HQ possessed, was obtained from the NASA/HQ Program Manager.

5.2.2. Other Data Sources: NASA/HQ furnished data concerning the following programs:

- o OSO-I
- o ATS-F
- o Nimbus-G
- o Pioneer-Venus
- o Atmos.Expl'er.
- o HEAO A/C

In addition to the above, NASA furnished assorted data concerning general NASA

contracting practices, NASA Pops, PADs, and such other data as the COR thought pertinent to the study.

5.2.3. Data State: Despite the expenditure of considerable time and effort, LMSC was unable to obtain a complete set of data for any one program. Such a data set would have consisted of the early NASA program decisions,the Phase A Program definition, early contractual surveys of possible contractors, the RFP, the contractors' responses to it, the contract data concerning selection& award, early funding agreements, the contract document itself, subsequent changes to the contract scope and intent, programmatic records of performance, contract finalization, fee awards, and detailed cost breakdown by contract period. Data provided by NASA were fragmentary, and data of the type desired, and solicited by letter from the several contractors involved in the NASA programs listed, were either not available; or again, fragmentary. During the data acquistion phase effort was expended to obtain data whose subject was programmatic costs of SE&I Activity, and GSE used for programs. These efforts proved only partially successful.

5.2.4. Data Problems: In analysing the data that were available, it became evident that specific data concerning GSE were almost unavailable in usable form. WBS reporting tended to list GSE as a single block against which costs for this item were collected. No GSE lists of any value were kept as a program record, nor were valid cost data available by specific GSE item. GFE was seldom identified as separate from GSE, nor, with the exception of MVM-73, was GSE inheritance, program-to-program readily traceable. In an attempt to obtain more GSE data, a GSE questionnaire was compiled. This questionnaire, which will be treated later in Section 7 of this report was both mailed to participants, and also hand delivered during the course of the PER Survey. The responses to that survey will be discussed in Section 7, but essentially, data received were insufficient to allow the GSE task to be continued as originally planned. Similar difficulties accompanied the data acquistion task for the SE&I portion of the study, as discussed in Section 6 of this report, such that the scope of this portion of the study activity could not be as extensive as was planned.

5.2.5 Data Usage: An integral part of Study Task 1, was the analysis performed on the P 71-2 (SESP) data. At NASA request, the following activity was completed using the SESP data:

* (a) A comprehensive listing was made of P 71-2 SESP components

* (b) A listing was made of Component Sources, Source Points of Contact, and component spares.

(c) A listing of component design drawings, together with drawing copies was made, and where possible, the listing was cross-referenced with a listing of component costs.

(d) A detailed Cost Breakdown of the SESP program costs was made and included in this listing of costs were data concerning program performance, program history as affecting costs, and program schedules. All of these data were combined into EM LCPP-10,1 May/75.

(e) EM-7 was prepared which gave a complete as possible program history of P 71-2 (SESP), from both the technical viewpoint, the componentry listing used, and the overall design disclosure.

(f) EM-11 was prepared, May 15/75, which furnished a synthesized analysis of the cost saving which might have been effected by the application of Low Cost Practices to the SESP program

* These items were furnished at NASA/HQ request to Aerospace Corp, for inclusion in the NASA Components Data Book, which that company was under NASA/HQ contract to prepare and publish under the title C.A.S.H.(Catalog of Available Standard Hardware)

5.2.5.1. Uses of Other Data: The other programmatic data listed herein were used to the extent possible to perform the remainder of the analyses undertaken in support of Study Task 2. MIL-STDs, Handbooks, Specifications, NASA Handbooks, STDs, Specifications, DoD Directives, and Industry Standards were used as required, and these were furnished from the LMSC data bank.

5.2.6. Conclusions: Apart from the scarcity/unavailability of programmatic data which impeded the progress of some tasks of this study; a conclusion emerged clearly from the Data Acquisition task. Detailed cost data of the type essential to permit visibility into historical program practices, do not exist to any marked degree. The data available were not acquired and analysed in a manner such that visibility into program practices was possible, as,until the recent NASA emphasis on low costs, aerospace companies reporting data, have neither been contractually required, nor made it a practice to descend to minute levels

of cost data recording/reporting.

5.2.6.1 Outcomes Affecting the Study: The lack of complete data, and the state of the data available led to a re-direction of the LCPP study. This re-direction took the following form:

1. The task of generating PERs was curtailed due to lack of suitable data.
2. The SE&I analysis was completed to the best degree possible, but was curtailed due to lack of suitable detailed data.
3. The GSE analysis was completed similarly, but the task was also curtailed due to lack of suitable detailed data.

* 4. The specifications analysis task continued for additional specs.

* 5. A qualitative review was made of the impact of low cost practices upon program risk, and a survey of the state-of-the art-techniques for quantitative determination of program risk was prepared. Outputs of this task were EMs LCPP-15 & LCPP-19 and the details of this task are discussed in Section 9 following.

* 6. The need was envisioned for a comprehensive WBS, so constructed as to serve as:

   (a) A Standard WBS for NASA unmanned space programs

   (b) permit acquisition of detailed program costs by hardware and labor function costs.

   (c) Demonstrate the cost impact of applying low cost practices.

   By direction of NASA; work was to begin on this task immediately, and a description of this task forms Section 8 of this report. The EM generated describing progress of this task is LCPP-17.

* Items listed above, and identified with an asterisk form the re-directed tasks of the study as proposed by LMSC, and approved by NASA/HQ June 1975.

SECTION 6

SYSTEMS ENGINEERING & INTEGRATION (SE&I) IMPACT ANALYSIS

6.1 Analysis Objectives: There were three (3) objectives associated with this analysis:

(1) Determine the Costs of SE & I activity

(2) Identify the functions and practices associated with, and contributing to these costs.

(3) Identify and recommend alternative practices, which when implemented, will reduced SE & I costs to future space programs.

6.2. Analysis Approach: The approach to the analysis was as follows:

- o List and describe the typical SE & I functions performed
- o From historical programmatic data, supplemented by estimates as necessary, determine the costs involved for each function, summarizing the totals by SE&I function and program.
- o Determine the percent of TPC for each SE&I function, the percent of each program, and the average for all programs considered.
- o Propose alternate SE&I approaches/practices believed to reduce costs, or eliminate some cost items.
- o Estimate the cost savings expected to result from implementation of the recommended Low Cost Practices.

6.2.1 Analysis Assumptions: Modified practices suggested for application to the historical programs used as a data base, could be applied with equal ease to current similar programs, was the first assumption made. The second assumption was that the practices suggested could be implemented on Shuttle era payloads, using modular spacecraft, and refurbishable/re-usable standard components, and/or modules.

6.3. Analysis Problems: Only very limited data at program top levels were available, and these were from the programs listed in Fig 6.1 Page 6.2. Another difficulty was that the top level data available from the programs listed, contained very few breakdowns by function and associated cost. Data for the paperwork integration activity were almost non-existent, and the only integration costs available concerned hardware integration rather than paperwork. Since hardware integrations costs were not to form a part of this analysis, separation of the hardware and software costs proved impossible, and with the proscription against hardware costs also, the integration task was deleted from the

Program	Agency	Contr.	WBS Item Assigned	Gen'l. Descr. Avail.	Categ. Brkdn. Avail.	SE&I Plan Avail.	SE&I O.A. $ Avail.	SE&I Funct. $ Breakdwn	SE&I Categ. $ Breakdwn
ERTS	GSFC	GE	-	-	-	-	-	-	-
Nimbus - G	GSFC	GE	-	-	-	-	-	-	-
OSO-I	GSFC	Hughes	N	Y	Y	Y	Y	N	N
HEAO - A, B, C	MSFC	TRW	Y	Y	Y	Y	N	N	N
Pioneer-Venus	ARC	Hughes	-	-	Y	-	-	-	-
Pioneer 10, 11	ARC	TRW	-	-	-	-	-	-	-
ATS-F	GSFC	Fairch.	Y	N	N	N	Y	N	N
AE	GSFC	RCA	Y	Y	N	N	Y	(Y)	N
MVM-73	JPL	Boeing	Y	Y	N	N	Y	N	N
SMS	GSFC	Philco	-	-	-	-	Y	N	N
71-2	AF	LMSC	N	N	Y	N	Y	Y	Y

N = None Y = Yes (data available) (Y) = Yes (some data)

Fig. 6-1 SE&I Data Sources/Availability

analysis; by necessity. The final major problem with the analysis was that for the data base used, there were marked inconsistencies in practices in the areas of Program Definition, RFP and WBS preparation, and program record-keeping.

6.4 Analysis Outcomes: Early in the analysis it became apparent that the term "Systems Engineering" is very broad in meaning, and what is actually undertaken under this category by aerospace contractors varies very widely from one contractor to another. Similarly, costs acquired and reported under that catgory are subject to considerable variation, program-to-program; even though the programs are quite similar in nature. Fig. 6.2 appearing on Page 6.4. illustrates such variation, and suggests that where high inheritance of technology, and equipment from a preceeding program or programs, exists, it has a material effect on systems engineering costs.

System Engineering even varies in formal definition by the Government specifications imposed to define it. There are similarities and overlaps present in the two major system engineering documents , MIL-STD-499 and MIL-STD-881 which are imposed on programs, but there are also dissimilarities and differences. The inconsistencies examined , and recorded in some detail in the EM produced covering the subject, carry over into the production of the WBSs produced for the programs examined during the course of the analysis; e.g. at one extreme is the HEAO program with a highly detailed WBS inclusive of integration activities, and at the other is the AE program which is far simpler as a WBS, and included the three basic systems engineering functions only.

6.4.1 Cost Outcome: In an attempt to demonstrate the disparity,program-to-program of systems engineering charges versus program costs, a graphical set of relationships was produced, and for reader convenience, this appears on Page 6.5. as Fig 6.3. This figure also sets forth the major conclusions arising from this graphical exercise.

6.5. Conclusions: EM LCPP-8 (issued April 21/75) had a number of minor conclusions, and two major ones appended. The two major conclusions are reproduced below, as follows:

- o It would appear that NASA has been paying from 2.8 - 11.4% TPC (for each of the programs reviewed) for something called Systems Engineering, sometimes called Systems Engineering & Integration.

Spacecraft Program	Cognizant Agency	S/C Contract	System Engr. Cost	Total Program Cost	Avg. Year Expend.	S.E. % of T.P.C.*	Type** Program
OSO-I	GSFC	Hughes	$2.772M	$34.281M	71/72	8.1%	F/O
ATS-F	GSFC	Fairchild	4.3 (E)	75.4 (E)	71/72	5.7%	F/O
SMS	GSFC	Philco	3.117	42.027	71/72	7.49%	New
AE	GSFC	RCA	0.856	21.761	72/73	3.9%	F/O
MVM-73 (Part #2 Only)	JPL	Boeing	1.075	38.597	71/72	2.8%	New: HI
71-2	AF	LMSC	1.378	12.026	70/71	11.4%	New: HI

Average

*Spacecraft Contractor Program

**HI = High Inheritence

(E) Estimated

Fig. 6-2 Costs of System Engineering

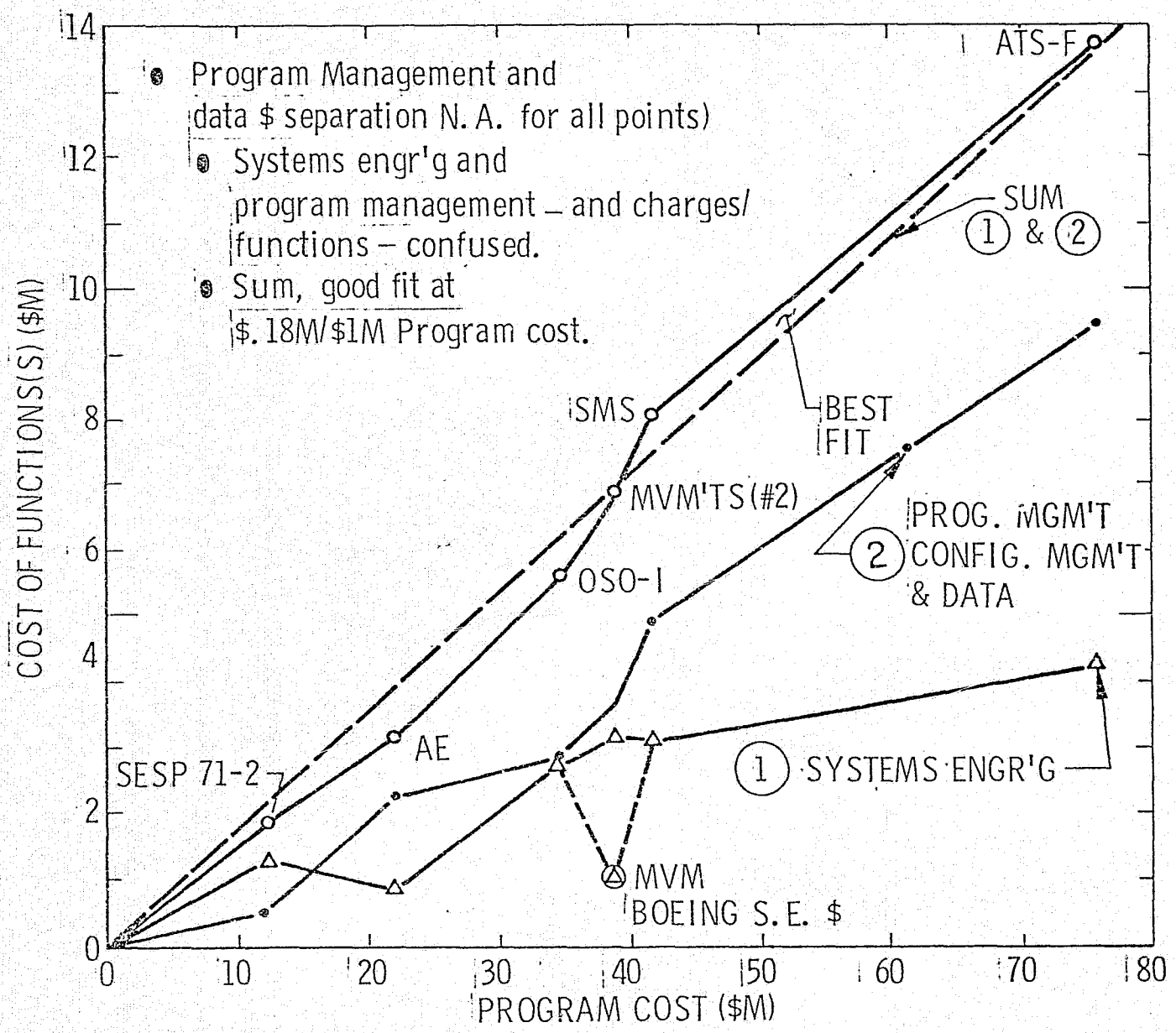


Fig. 6-3 Systems Engr'g Charges Vs. Program Cost

The definition of what that "something" is, is quite vague, and the associated cost accounting tracking for the task is even more vague and tortuous.

- o NASA practices in structuring Complete WBSs,(which have but a single place to charge each SE&I task) must be improved before accurate practice/cost evaluations can be made.

6.6 Recommendations: Arising from these two major conclusions LMSC made the following recommendations:

- * o Discontinue the SE&I analysis, until more, and better historical data become available.
- o Develop a NASA-wide definition of SE&I functions, so that overlaps, such as those encountered with other functions such as subsystem engineering, management, configuration management, and data management, can be eliminated, and better clarity can be obtained.
- * o Develop a standardized WBS, to permit charging SE&I charges in a manner which ensures separation from charges relating to other functions; and also permits recording of cost variations arising from variations of SE&I practices from program-to-program.
- o Include these recommendations concerning the WBS, and the NASA-wide definition of SE&I, together with specific instructions that they be used by future programs, in all future program RFPs.

* As has been stated elsewhere in this report, the item highlighted by the asterisk was recommended during the mid-term study review. The WBS recommendation was authorized as a new study task by NASA/HQ.

SECTION 7

GROUND SUPPORT EQUIPMENT (GSE) IMPACT ANALYSIS

7.1. Analysis Objectives: This analysis, which formed part 3 of Study Task 2, had two major objectives. These were:

(1) Definition of the approximate cost contribution of GSE to spacecraft programs.

(2) Identification of the cost impacting practices which lead to higher or lower GSE costs on a given unmanned spacecraft program.

7.2. Analysis Approach: The analysis included in its scope all program-peculiar GSE used at all locations (contractor and sub-contractor plants, NASA and/or contractor field sites, and launch base; up to and including launch). Government furnished GSE was included in the analysis, but post-launch support equipment used at the launch site, tracking stations (data links), and data reduction centers, were excluded.

The Overall category of GSE was then sub-divided into several categories such as:

- o Test & Checkout equipment
- o Transportation & Handling equipment
- o Servicing equipment
- o Launch Control/Monitoring equipment.

These catgories were further divided into equipment groups by type.; i.e. Test & Checkout equipment includes, manufacturing test equipment, simulators, test support equipment such as chambers & test fixtures, and integrated spacecraft, and systems test equipment.

With the equipment categorized, the next step was to undertake three sub-tasks as follows:

(1) Determination of type, quantity, and usage (location, transfers & redundancies) of GSE used on historical and current spacecraft programs.

(2) Tabulate historical costs of GSE, by major categories, and individual equipment items where possible.

(3) Analyse the cost impact of specific GSE practices.

Sub task 3 included consideration of the following GSE practices:

- o Use of commercially available components
- o Specifications imposed by the customer and the contractors
- o Degree of standardization, within a program & among NASA centers
- o Usage of common equipment for launch vehicle & payload
- o Scheduling of use for the same GSE item (geographical transfer vs item redundancy)

Finally, the average cost reduction was estimated for alternate low cost practices as synthetically applied to current unmanned space program hardware, and modularized future spacecraft with refurbishable/reusable components.

7.2.1. Analysis Data Sources: Data were obtained from a number of programmatic sources as illustrated by Fig. 7.1 Page 7-3. As may be seen from the figure the data were fragmentary, sparse, and of a -"Total program general lump sum type" Very little cost detail was available from these programs.

A GSE Questionnaire was prepared for distribution to NASA centers, and contractors, but this was oriented toward GSE practices, rather than the collection of detailed costs, and although it did furnish cost insights for 6 programs, actual cost fine detail was once more conspicuous by its absence. The data lack was further complicated by a lack of commonality in GSE categories, descriptions, and cost groupings, program-to-program.

7.2.2. Questionnaire Outcomes: Responses to the 34 page multiple-choice type questionnaire were received from one NASA center, and six (6) spacecraft program contractors. Highlights of thse responses were as follows:

- o On a nine spacecraft program basis, contractor supplied GSE averaged 4.7% of TPC. Questionnaire results based on 6 programs revealed the same figure, although the detailed responses from 4 programs showed contractor supplied GSE at 5.3% TPC.
- o Based on the detail supplied by four (4) programs, the GSE/GFE breakdown is as follows:
  - o Contractor supplied GSE..... 84%
  - o Govt Furnished GSE (GFE).... 16%

The figures listed do not include existing GSE in possession of the contractor, only that bought new for support to the programs considered.

Program	Agency	Contr-actor	GSE Q		Detail GSE List	Equip. Categ. Desc.	Genl. Desc.	GSE Plan	Cost Data		
			Sent	Answ.					O. A.	Categories	Funct.
ERTS	GSFC	GE	Y	N	N	N	N	N	N	N	N
Nimbus-G	GSFC	GE	Y	N	Y	N	N	N	N	N	N
OSO-1	GSFC	HAC	Y	Y	N	Y	Y	N	Y	Y	Y
HEAO-A, B, C	MSFC	TRW	Y	Y	Y	Y	Y	Y	Y	Y	Y
Pioneer-Ven.	Ames	HAC	Y	N	N	N	Y	N	N	N	N
Pioneer 10, 11	Ames	TRW	Y	Y	N	N	N	N	Y	Y	N
ATS-F	GSFC	Fairchild	N	N	(P)	(P)	N	N	Y	N	Y
AE	GSFC	RCA	Y	Y	(P)	N	Y	N	Y	Y	Y
MVM-73	JPL	Boeing	Y	N	Y	N	N	N	(P)	N	N
SMS	GSFC	Philco	Y	Y	Y	N	Y	N	Y	Y	Y
71-2	AF	LMSC	Y	N	Y	Y	Y	Y	Y	Y	Y
P-50	AF	LMSC	Y	Y					Y	Y	Y

KEY: N = No Data Available

Y = Data Obtained

(P)= Partial Data Obtained.

Fig. 7.1 GSE Data Sources and Availability

Figure 7.2 furnished on Page 7-5 shows a Cost Extrapolation of the average costs of GSE, considering only the major categories of equipment. The values shown are the break-out cost details tabulated under the outcomes paragraph.

7.2.2.1. Contractor GSE Cost Break-Down: From the outcomes of the questionnaire it was possible to gain some insight into the manner in which overall GSE costs are incurred by contractors. While these values are necessarily only average values for the relatively few programs examined, they represent the best data available currently on this subject.

Contractor GSE Cost Breakdown

(Percent)

	% Range	Ave. %
Planning and Requirements	3-5	4.4
Design Engineering and Development	10-40	22.8
Sustaining Engineering	0-5	1.4
Procurement/Purchase/Lease	10-50	32.6
Manufacture of New GSE	10-30	16.5
Modification of Existing GSE	3-5	4.3
Qualification testing	0-5	1.0
Acceptance testing	0-5	1.4
Installation and Checkout	0-5	2.2
Maintenance	0-10	3.2
Documentation	5-20	10.2
Total GSE		100.0%

Source: GSE questionnaire, 5 S/C programs.

7.2.2.2. Also from the questionnaire, and confirmed by NASA supplied data, it was possible to make a cost comparison among the several items of GSE supplied by the contractors involved in 8 spacecraft programs. This comparison is tabulated in Fig 7.3, furnished on Page 7-6.

MAJOR CATEGORY	Contractor GSE		GFE GSE		Total GSE Cost	
	%	Extrap. $ M	%	Extrap. $ M	$	Extrap. $M
HANDLING & TRANSPORT EQ.	12.6	0.33	2.0	0.01	11.0	0.34
SERVICING EQ.	7.6	0.20	2.0	0.01	6.8	0.21
TEST & CHECKOUT EQ.	79.8	2.07	96.0	0.48	82.2	2.55
TOTAL	100.0%	$2.60M	100.0%	$0.50M	100.0%	$3.10M
PERCENT OF TOTAL PROGRAM COST		5.3%		1.0%		
SHARE OF TOTAL GSE		84%		16%		100%

* Based on four spacecraft programs. Excludes all contractor and GFE GSE costs which are sunk or capitalized by contractor.

Fig. 7.2 Average GSE Costs Extrapolated by Major Category *

Spacecraft Program	Cognizant Agency	S/C Contract	GSE Cost M of $	Total Program Cost M of $	Av. Year Expend.	GSE (3) % of T. P. C.
OSO-1	GSFC	Hughes	$1.05 (1)	34.281	71/72	3.1%
ATS-F	GSFC	Fairchild	10.1 (4)	110.3 (4)	71/72	7.7% (4)
SMS	GSFC	Philco	1.985 (5)	44.2 (5)	71/72	4.5% (5)
AE	GSFC	RCA	.729	21.761	72/73	3.3%
MVM-73 (Part 2)	JPL	Boeing	2.067(2)	38.597	71/72	5.4% (2)
71-2	AF	LMSC	.921	12.026	70/71	7.6%
Pioneer F&G	AMES	TRW	4.3	50.0	70/73	8.6%
HEAO	MSFC	TRW	2.5 Est.	80.0 Est.	74/77	3.1%

(1) Excluding test equipment for experiments
(2) Excluding some subsystem support equipment and system test equipment
(3) Spacecraft contractor program
(E) Estimated
(4) Excluding systems test complex
(5) Excluding tracking station equipment ($\approx$ $810K)

Fig. 6 - Comparative Costs of Contractor Supplied GSE (as charged to the program)

7.3. Major High, and Low Cost Practices: From an examination of the available data it would appear that there is a major High Cost Practice associated with the programmatic use of GSE. This practice may be generalized as:

> The change in GSE requirements due to changes in the spacecraft, and to a lesser degree, due to some changes which occur in program planning and spacecraft experiment/payload changes.

In the area of Major Low Cost Practices, the following practice was observed:

> Extensive GSE inheritance is applied to spacecraft programs by the contractors concerned. For the programs examined, less than 50% of the total GSE value is charged to the program by any given contractor.

A highly subjective breakdown of this Low Cost Practices is furnished below:

Contractor supplied GSE charged to program	44%
Contractor supplied GSE not charged to program	16%
GFE GSE new or modified	9%
GFE GSE sunk cost	30%
Surplus GSE at replacement value	1%
Total ROM GSE Cost (excl. post-launch GSE)	100%

7.4. Conclusions: Three major conclusions were drawn from the GSE analysis task:

1. There is a definite trend toward low cost practices in the GSE area, evidenced by the high inheritance of GSE, program to program.
2. Significant cost savings can be made in this programmatic area if better information on what exists, where, and in what quantities, is disseminated to NASA contractors and NASA field centers. NASA is approaching this data dissemination task by preparing a GSE Equipment Visibility System (EVS). Further, as this listing is available, RFPs will require the use of the GSE inventory, and require trade-offs of cost in cases of deviations.
3. Maximum use of GSE existing, is expected to reduce the programmatic costs approx. 50%

SECTION 8

NEW-LOOK STANDARDIZED WBS

8.1. Task Objectives: As initially planned, the objectives of this task were to generate:

(a) A candidate "New-Look" WBS.

(b) A Users' Handbook.

The purpose of these documents was to afford better visibility into the work performed on NASA programs by contractors, and NASA itself, and, in the case of the Handbook, to provide NASA with the capability to implement the new WBS on future spacecraft programs.

Following the NASA/LMSC review of the preliminary concept of the scope of the task, early investigation revealed that the objectives as stated above, would be unattainable within the constraints of schedule and budget available for this brief study period. LMSC therefore proposed the following modified objectives for the task, and obtained NASA concurrence to proceed with their implementation:

(a) Analyse and document the merits and difficulties associated with the development, and implementation of a standardized WBS.

(b) Establish a means of tracking/recording data suitable for the evaluation of the cost impacts of Low Cost Practices, with any type of WBS.

8.2. Analysis Background: Throughout the course of the Low Cost Program Practices study, one of the major aims has been the identification, and quantification of High Cost Practices, applied to both past, and on-going, NASA spacecraft programs of the unmanned type. Many High Cost Practices have been identified successfully, but many others are suspected to exist, and these have not proved quantifiable from historical programmatic records. LMSC sampled cost, and other programmatic data from thirty-nine (39) NASA and DoD programs, and in the process of analysis of these data, it became evident that the data were inadequate to permit quantification of program practices. Further verification of data inadequacy was revealed by a survey of more than seventy

(70) functional managers and cost analysts within NASA, and the aerospace industry. Of those personnel surveyed, fifty-seven percent (57%) were of the opinion that data available were inadequate for quantifying impacts of program practices, nineteen percent (19%) believed that the data were adequate, and the balance expressed no opinion.

Some NASA practices related to the implementation of program WBSs contributed directly to the the lack of adequate cost records, and it became evident that traditional practices preclude the quantification of either High or Low Cost-Driving Practices, in the several areas of:

- o Systems Engineering and Integration
- o Flight Support Equipment
- o Ground Support Equipment.

The scarcity of historical data, its adequacy when available, and the fact that NASA is in the process of conversion to more cost effective methods of conducting near-term, and future space programs, gave rise to the conclusion that work should begin immediately on the development of a NEW-Look WBS. This programmatic work/cost analysis tool, together with its associated Implementation Directives for Low Cost Practices, will be of material benefit in the prosecution of NASA policies of cost effectiveness for all future programs.

8.2.1 Analysis Problems: Several problems were encountered as this analysis developed. These problems are listed briefly below, as they were instrumental in the decision to modify the scope of the WBS analysis task from that originally planned.

(1) Unavailability of personnel. Due to the pressures of continuing the analyses undertaken in the areas of specifications, SE&I, GSE, and the documenting of the PER Survey results, work was deliberately delayed until the last quarter of the study. At that time, personnel originally scheduled to perform the analysis were unavailable. A contributory factor in the delay of the task, was an injury accident to the Study Program Manager, under whose supervision the work was to be performed.

(2) Underestimation of Task Scope: At the outset of the analysis, it was believed that the LMSC version of the CSCSC technique, CASPER, a computerized cost acquisition and tracking program validated by the

USAF; would be acceptable for use with the evolving WBS. Work was commenced on the preparation of work packages for both program functional tasks, and hardware down to the level of components. As this task progressed, and the level of detail proliferated, as well as the number of inter work package functional relationships it became obvious that the overall process of computation, tracking, and reporting of all program effort costs was combinatorial in nature. CASPER provides excellent cost acquisition and summing capability for work packages of the type traditionally used with WBS operations, but these are additive in nature, and unfortunately, combinatorial routines are not implicit in the program. The program has almost infinite capacity for handling discrete data, but when all possible permutations of the many combinations of functional tasks, and the hardware/software production costs were considered, an unmanageable number, or more than 50,000 cost accounts resulted. The human effort involved in manually recording such a large numerical population, and accurately segregating one from another, is costly not only in time expended, but also in terms of the high probability of error.

(3) Funds were not available, nor would the study schedule permit reprogramming CASPER to handle combinatorial routines.

8.3 Summary of Outcomes: An initial concept was developed on the basis that any NEW-LOOK Standardized WBS would, of necessity, apply to not only work at aerospace contractors; but also throughout all NASA centers involved in spacecraft programs. This initial concept is shown diagrammatically in Fig.8.1 Page 8-4. Continuing work along the lines shown in the figure was infeasible for the reasons stated above, and thus the modified task objectives were substituted. Outcomes of these are as follows:

- o LMSC did develop a Standardized WBS concept for unmanned spacecraft programs, which, when fully developed, would be adequate for NASA requirements.
- o Also developed were preliminary methods for recording Low Cost Program Practices used in conjunction with detailed program work-

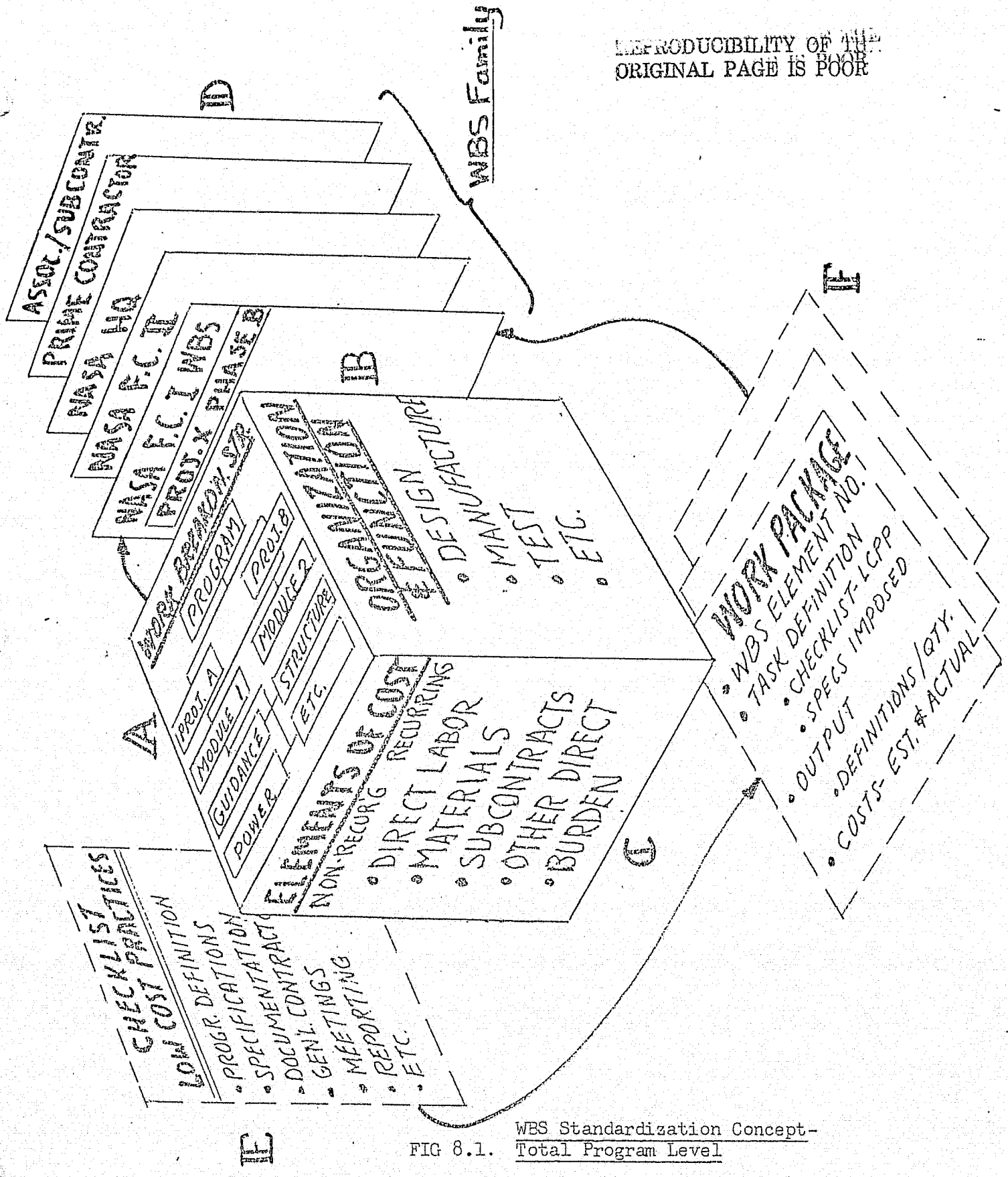


FIG 8.1. WBS Standardization Concept-Total Program Level

-packages, and to summarize work package quantified data. Both of these work package oriented concepts are essential for the evaluation of, and the quantification of, the cost impacts of Low Cost Program Practices. The concepts can be used, with, or without a Standardized WBS.

8.4. Task/Analysis Conclusions: Among a number of conclusions to be drawn from the work performed on this Study Task, there are several of significance. These are listed as follows:

- o LMSC under-estimated the task magnitude implicit in the development of a Standardized WBS. A complicating factor in the task was the attempt to incorporate requirements for tracking/recording details which would permit quantification of Low Cost Program Practices.
- o Both a verified initial concept, and a firm basis for the development at some future date of a Standardized WBS were outcomes of the task as conducted to-date.
- o The concept established for standardization will provide adequate flexibility, within the work-package framework envisioned, to accommodate the small differences expected to exist among future unmanned spacecraft programs.
- o Traditional NASA practice has been to spend several millions of dollars per annum, in the tailoring of a new family of WBSs for each new program undertaken. Implementation of a Standard WBS could save this appreciable sum of money for use elsewhere on unmanned spacecraft programs.
- o Implementation of the concepts defined in this study, not only provide improved program visibility into cost/performance; but also furnish additional records for better evaluation of program practices. Further, there will be no disturbance of existing NASA cost collection, and reporting systems.
- o Cost effective development of a fully functional Standard WBS will require active participation of NASA personnel on a day-to-day basis. This will assist materially in the formulation, and co-ordination of intra-mural decisions, and definitions.

8.5. Task Recommendations: LMSC recommends that NASA:

- o Continue efforts to develop and subsequently implement a standardized family of WBSs for unmanned spacecraft programs.
- o Establish a small team of NASA and contractor personnel to pursue full-time development of an integrated family of Standardized WBSs, and the speedy implementation of such a family for all future effort on unmanned spacecraft programs; both NASA and contractor work being covered by the family aforementioned.

For those wishing to study the WBS task in depth, the full text is contained in EM LCPP-17, which is included in the Appendix to this technical report.

SECTION 9

RISK IMPACT OF LOW COST PROGRAM PRACTICES

9.1 Analysis Objectives: This analysis has been undertaken as the fifth subtask of Study Task 2. As planned originally, the task had two objectives:

(1) To list the Low Cost Practices identified during the course of the study, and against each practice listed formulate qualitative assessments of their impact upon programs. These qualitative assessments were to made in terms of High, Medium, or Low Risk to Program Performance, Program Cost, Program Schedule. Rationale for each judgement listed against each practice was to be appended, and the change in Risk Impact from the usual routinely applied high cost practices to the recommended Low Cost Practices was to be assessed as Risk Increase, Risk Decrease, or No Change in Risk.

(2) To list type of Programmatic data required for the assessment of risk on a quantified basis, and to provide a preliminary plan for the acquisition of such data.

9.1.1. Task Objective Substitution: As the study progressed it became increasingly apparent that programmatic data of the types required for assessment of program risk quantitatively, simply did not exist. Acquistion could not be undertaken therefore, nor could valid planning for this task objective. A substitution of objective was made, with NASA concurrence. Objective #2 then became:

- State of the Art (SOTA) Survey, Quantification of Program Risk.

9.2. Analysis Approach: As with all the analyses undertaken, the approach was to prepare EMs covering the salient points of the analysis. Two EMs were prepared; EMs LCPP-15, and LCPP-19, issued to NASA in draft form October 8/75, and November 20/75 respectively. The former treated the qualitative aspects of program risk analysis, and the latter furnished the details of the SOTA survey.

9.2.1. Qualitative Assessment Approach: All of the Low Cost Practices identified to date were listed by categoric groupings. The categories chosen were the several areas of spacecraft program activity, each of which contained a number of Low Cost Practices.

The program activities categories are:

Activity Area/Category	Qty of Low Cost Practices
RFPs	7
Design	8
Documentation	7
Manufacturing	2
Program Definition/Changes	5
Program Management	9
Quality Assurance	5
Reliability/Maintain'y/Safety	0 (reserved for later edit'ns)
Specifications	5
Testing	2

Selecting examples at random:

RFPs..... LCP #1-3. Use RFP to encourage Lower-Cost Response
Design..... LCP #2-6 Higher Design Margins-Less Testing
Program Management... LCP #6-2 New set of Low Cost CERs
Quality Assurance.... LCP #7-5 Reduce quantity of Inspection-Points
Specifications..... LCP #9-5 Use of a Reduced "Standard" Spec.-List.

For reader convenience, and again selecting an example at random, a completed copy of the standard Work/Data Sheet developed for use in qualifying the Low Cost Practices, is furnished on Page 9-3 as Fig.9.1

9.2.2. State-of-the-Art Survey, Quantification of Program Risk Approach:

As the title implies, the approach to this analysis segment consisted of a survey of recent publications having direct bearing on the subject. Each listed reference was scrutinized to determine approach hypothesis, assessment methodology, degree of mathematical rigor, and applicability to the assessment of spacraft program risk. More than 40 publications were scrutinized, and their salient points were digested and included in the EM, together with graphs, statistical formulae, and major conclusions excerpted from the publications.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE Page 1 of 1

1. LCP No.: 7-2 2. CATEGORY: QUALITY ASSURANCE

3. LOW COST PRACTICE: Use of Contractor Quality Manual - Low-Cost Version

3.1 Request contractor to prepare and submit a "low-cost version of his Quality Manual which features low-cost practices listed here and elsewhere and includes a basic program Quality Plan.

3.2 Validate the new Manual and permit use in subsequent contractor proposals in lieu of submitting a new program-peculiar Quality Plan. Require that program-peculiar changes or deviations be submitted as an addendum to the Low Cost Quality Manual.

4. RESULT OF IMPLEMENTATION:

4.1 Eliminates need to submit a new Quality Plan with each proposal (large degree of redundancy among various plans).

4.2 Use of a low-cost Quality Manual would be a strong forcing function toward reduction of program costs.

4.3 Use of validated contractor Quality Manuals would accelerate implementation of low-cost practices.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	All Other	M
Manufacturing	☐	Materiel	☐	Qual.Assur.	H		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule No Change Cost No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Many of the Quality Assurance functions can be reduced without degrading the product quality or performance. Also, each of the elements of a new low-cost Quality Manual would be reviewed carefully by NASA before validation, lowering the probability that any unforeseen program risk would be incorporated. Therefore, no change in program risk will result

Fig.9.1. Sample Data Sheet

9.2.2.1 SOTA Survey Outcomes/Conclusions: Several conclusions resulted from the survey. While the full text descriptive of the survey is available in EM LCPP-19, included in the Appendix; the conclusions are repeated herein, as a convenience to the reader. The conclusions are:

1. Apparently, there is no existing methodology directly applicable to the prediction of quantified risk to program performance and schedule.
2. Three (3) sets of data are required to make statistically valid assessments of program risk:
   - o Reasonably complete design definition of proposed new program hardware.
   - o Accurate estimates of the cost of the several, and various, elements of the new program. Detailed estimates are required down through the component level of the WBS structure.
   - o Historical programmatic data from noth "Normal", and "Low Cost" programs. As a minimum, these data should include:
     (a) Performance Requirements, for vehicle, subsystem, and component levels.
     (b) Schedule Information, prepared preferrably in PERT, or VERT type networks.
     (c) Cost Data/Estimates, at vehicle, subsystem, and component levels of detail.
3. All of the foregoing data should be available on a "standardized basis, so that summations, means, and standard deviations, can be determined. Such data would be used as risk bases for new programs, so that comparisons with historical program records can be undertaken.

SECTION 10

PROPOSED NASA POLICY (IMPLEMENTATION) DIRECTIVES

10.1 The NASA/HQ Low Cost Systems Office expressed the intention to prepare, and issue a set of policy directives, probably on an incremental basis, to facilitate the implementation of Low Cost Practices for NASA spacecraft programs. In compliance with this direction to prepare preliminary drafts of such directives, LMSC undertook to examine selected Low Cost Practices, and formulate them as potential NASA policies. The definitions, rationale, subject matter, and outcomes of this task, Study Task 3, were documented in EM LCPP-18 issued November 5, 1975. Appended to this EM were five (5) attachments, A,B,C,D,&E covering respectively:

- o Basic Policy for Implementation of Low Cost Practices.
- o Basic Policy for Low Cost Application of Specifications & Standards
- o Basic Policy for Lower Cost Documentation Requirements
- o Basic Policy for Improved Contract Program Definition, and Fewer Contract Changes.
- o Basic Policy for Lower-Cost-Driving RFPs

As there were no technological innovations in these directives rough drafts, and as further, these drafts were intended to act only as basic guides to NASA in formulating the final directives, neither the EM, nor the attachments to it are furnished in either the Appendix, or this report. Copies of the EM were furnished to NASA/HQ LCSO as per COR direction.